SECTION 16311

TRACTION POWER ELECTRICAL EQUIPMENT

PART I GENERAL

0.1 DESCRIPTION

A. This Section specifies the conditions and technical requirements for furnishing and installation of switchgear, rectifier transformer, rectifier and accessory equipment for traction service.

B. Installation includes the furnishing of all labor, materials, tools, equipment, facilities and incidentals necessary to complete the designing, manufacturing, testing, delivering, installation and commissioning of the following electrical equipment:

1. 15 kV switchgear assembly
2. Rectifier transformers
3. Rectifiers and accessories
4. 750 volt DC switchgear assembly
5. Anode (AC) and cathode (DC) buses
6. Negative equalizer bus and drainage board
7. 15 kV Circuit Breaker Control and Instrument Panel
8. Supervisory equipment
9. Station battery, charger and accessories

C. Contractor shall furnish, install and connect any additional components, parts, items and devices not specifically mentioned in this Section or shown on the Contract Plans, but necessary for the proper operation of the equipment in accordance with the intent of the Contract Documents at no additional cost to the Authority.

0.2 DESIGN CONFERENCE

A. Contractor shall start detail design and drafting work for all equipment immediately upon Notice to Proceed and shall process design work to completion without delay and without regard to normal manufacturing schedule.

B. A Design Conference shall be arranged in the Metropolitan Boston area as directed by the Engineer. The Design Conference shall be scheduled so that it can be completed within 90 days from the Notice to Proceed. It is estimated that the Design Conference, dealing with the design and

manufacturing of traction power and substation auxiliary equipment, will take not more than two full working days, provided the Contractor will produce the data and drawings specified herein in full compliance with the Specification requirements. The Design Conference will be attended by the Engineer, Authority's Consulting Engineer for the Project, Contractor's Project Manager, Contractor's Power Engineer and on an as-needed basis, technical personnel from major equipment manufacturer. All Contractor's costs associated in arranging and attending the Design Conference shall be borne by him.

C. A minimum of 30 days prior to the Design Conference, Contractor shall submit the following for Engineer's review:

1. Certified overall dimension drawings showing weights and bases of all equipment covered by the Contract.

2. Complete design calculations as specified in Part 2 - Products, of this Section for Engineer's review and comments. Design details are to be approved by the Engineer in accordance with this Specification.

3. All pertinent information of equipment proving the general compliance with the Specification requirements. The submittal shall include published product literature showing construction features of equipment offered, ratings of circuit breakers, reference list of users in USA and any other information useful in illustrating the compliance with the Specification requirements.

4. Performance data of rectifier main DC circuit breaker during the operation on forward current at rated, overhead and short-circuit condition with and without polarizing supply applied and on reverse current, with and without polarizing supply.

5. Sketches or drawings clearly showing the conceptual design of the ground and test device associated with the 15 kV switchgear, including the listing of components.

D. During the Design Conference, Contractor shall provide the following:

1. Detailed engineering and design schedule and schedule for submittal of drawings for review, together with the detailed list of drawings to be submitted.

2. Manufacturing plan, specifically showing material planning for equipment, estimated period of manufacturer, planned date of completion and scheduled date of witnessing of tests.

0.3 REFERENCES

A. The Contractor shall comply with all applicable regulatory requirements, national codes, and technical references and publications listed in Section 16050 of these Specifications.

B. Standards

1. All electrical equipment furnished under this Contract shall be in accordance with the latest applicable standards of NEMA, IEEE, ANSI, AAR, ICEA, OSHA, and UL with regard to material, design, construction and testing, except for variations as specified in this Specification.

2. Where any requirements specified herein or shown on Contract Plans exceed the above listed standards, the Contractor shall adhere to the more stringent standard. In case of conflict requirements between two or more standards, the decision of the Engineer shall be final.

C. Special Conditions

1. In case of non-U.S. suppliers, equivalent British, European, Japanese or IEC standards are acceptable, provided a tabulation is furnished citing the comparison between the applicable U.S. and the equivalent non-U.S. standards. In addition, the non-U.S. suppliers shall note where U.S. standards are not met for the evaluation and approval of the Engineer.

2. All equipment and materials furnished under Division 16 shall conform to all Federal, State, or Municipal Laws for ordinances, and if any requirement shown or specified conflicts with such laws or ordinances, the Contractor shall make such changes as are necessary to meet said requirements. The cost of such changes shall be borne by the Contractor and shall be included in the Contractor's original bid. Where any standards shown on the Contract Drawings or specified herein exceed the minimum standards set by law, the Contractor shall adhere to the higher standard.

3. Where materials or equipment are specified to conform to the standards of the Underwriters' Laboratories, Inc., or to be constructed or tested in accordance with the standards of the National Electrical Manufacturers' Association or American National Standards Institute, the Contractor shall submit proof that the item furnished conforms to such requirements. The label of, or listing by the Underwriters' Laboratories, Inc. will be acceptable as sufficient evidence that the item is in accordance with the Underwriters' Laboratory standards. A company listed as a member company of NEMA for an item under consideration will be acceptable as sufficient evidence that the item conforms to the requirements of the National Electrical Manufacturers' Association. In lieu of such stamp or certification label listing, the Contractor may submit a written certificate from any nationally recognized testing agency adequately equipped and competent to perform such services, stating that the items have been tested and that the units conform to the requirements listed hereinbefore, including methods of testing of the specified agencies. Conformance with the agency requirement does not relieve the item from complying with any other requirements of

the Specifications.

4. The equipment of this section shall be properly packaged for the shipping and handling required for the project. Such items as individual component packaging, layover packaging, crane-hoist packaging and the like will be provided as required.

0.4 SUBMITTALS

A. Drawings and Reference Data: The below listed drawings, diagrams, instruction manuals, etc. shall be submitted for all equipment furnished for the Substations, in accordance with the requirements in Division 1, Article 1.03, Section 01300. In addition, provide submittals as required in accordance with Section 01700, Contract Closeout, and Section 16804, Drawings and Tracings.

B. Within 45 days after the Design Conference Contractor shall submit the following:

1. Certified outline drawings of all major equipment, indicating overall dimensions, space requirements, location of control and protective devices on panels and reference tables to other drawings furnished. The submittal shall include the front and rear view of the AC and DC switchgear, rectifier transformers, rectifiers, supervisory RTU's and the 15 kV circuit breaker control panel, showing all door and panel mounted devices, equipment and device nameplates and door swings.

2. Certified floor plans of equipment, showing dimensions necessary for installing equipment, clearances from building structure, equipment base details, dimensions and weights of shipping sections.

3. Certified top and bottom views of equipment, showing available space for entrance of power and control circuit wiring from the top or bottom, as specified and entry of anode and cathode buses; for DC switchgear, clearance above from grounded objects and structures.

4. Certified section views of each non-identical unit showing buses and bus supports, location of circuit breakers and the ground and test device in withdrawn, test and fully connected position and the location of outgoing power and control terminals. Drawings must be in sufficient detail to illustrate accessibility for maintenance and for adjustments while energized.

5. Certified front view and side panel views of each non-identical control compartment unit, with control compartment door(s) open, showing internally mounted control devices. All devices shall be shown in their respective locations with identifying nameplates.

6. One line diagram of equipment supplied, showing all power and auxiliary circuits, protective devices, and the location of all current, potential and auxiliary transformers and shunts with the devices

energized by them.

7. Schematic diagram of transformer, rectifier, AC and DC circuit breakers, negative drainage contractor controls and power supply/battery charger power circuit connections, controls and alarms. Wire numbers shall be assigned to each schematic and elementary diagram so that each segment of the circuits can be identified on internal wiring diagrams of the equipment and on the interconnection diagrams. Wire numbers of similar schematics of different circuits shall be prefixed or suffixed to differentiate between the wires of separate pieces of equipment. Schematic diagrams shall be self-explanatory and shall be specifically prepared for this Contract and shall include AC schematic (three line) and DC elementary diagrams for all circuits.

8. Internal connection diagrams of devices, including watt-hour demand meters. Contact development of control, selector and instrument transfer switches, test switches and lockout relays.

9. Equipment trip and lockout schedule, in tabulated form.

10. Calculations of 125-volt DC control power requirements and for sizing of station battery and charger.

11. Calculations for sizing the inverter and static transfer switch.

C. After the return of the schematic diagrams marked "For Construction", or equivalent, the following drawings shall be submitted within 45 days:

1. General arrangement plans and elevation views of the Substation, locating all Contractor's furnished and installed equipment.

2. Bus duct layout plans, sections and connection details.

3. Composite one line diagram of the Substation

4. Connection diagrams of each non-identical unit showing the following:

   a. Terminal block arrangement, identifying each outgoing power and control terminal and showing interconnections between individual units and shipping splits of an equipment assembly.
   b. Internal wiring diagrams of rectifier transformers, rectifiers, AC and DC switchgear cubicles and circuit breaker draw out elements, negative equalizer and drainage board, 15 kV breaker control and instrument panel, and power supply/battery charger, showing electrical devices in their relative physical locations, left to right and top to bottom. Each wire and jumper shall be shown on the wiring diagrams. Terminal blocks for external control cable connections shall be shown in their relative physical locations. Inboard wiring connected to these terminal blocks shall be positively identified and marked so as to be

readily located at the device end. All wiring shall be identified with wire numbers shown on schematic and elementary diagrams.

c. Schematic or figurative type wiring diagrams which do not portray the physical wiring of the panels will not be accepted.

5. Equipment rating nameplate data.

6. Instrument transformer ratio, phase angle and excitation characteristic curves.

7. Protective device coordination curves:

a. Contractor shall submit graphic proof of protective device coordination of equipment furnished for the Substation. Coordination curves shall be submitted on a log-log paper showing relay and trip device coordination for all equipment furnished. Current values shall be shown on 13.8 kV base; a multiplier shall be noted for conversion to DC output current.

b. Coordination curves shall include plot of rectifier design capability and shall clearly indicate actual margin of coordination from breaker trip to design capability at each of 150%, 300% and 450% full load current and short circuit current, taking into account derating due to rectifier phase leg current unbalance and loss of one diode in each phase leg. In addition, the coordination shall prove that the rectifier equipment is capable of delivering maximum through-fault current for 1.5 seconds, or longer without exceeding the safe operation limits of diodes and other components within the rectifier package. Final co-ordination will be subject to Engineer's approval.

8. Certified outline drawings of battery charger, battery and battery rack; schematics and wiring diagrams of battery charger; battery and charger installation details and connection diagrams.

D. After the return of the schematic diagrams marked "For Construction", or equivalent, the following drawings, schedules and diagrams shall be submitted within 120 days:

1. Cable tray and conduit layout plans and sections.

2. Detail plan and elevation drawings of bus ducts; connections details and bill of materials.

3. Detail drawings of cable tray, conduit and bus duct supports.

4. Installation details of equipment and auxiliary devices.

5. Interconnection cable schedules and cable routing block diagram.

6. Bills of installation materials.

7. Cable tray loading schedule.

8. Renewal parts list.

9. Interconnection wiring diagrams, showing the terminal blocks of each individual unit, interconnections between each piece of equipment and each device installed external to the equipment. Interconnection diagrams shall show cable and terminal numbers, make reference to internal wiring of the equipment and note the drawing on which the cable run is continued.

10. Bills of materials of equipment, devices and accessories with catalog cuts of all devices and accessories listed.

11. Characteristic curves of circuit breaker trip elements and fuses, on log-log paper.

12. Equipment nameplate drawings for all equipment.

E. Upon successful completion of factory tests and at the same time the equipment is shipped for installation, the following documents shall be submitted:

Instruction materials for each piece of equipment, furnished, including installation instructions, operating instructions, maintenance manuals and recommended spare parts lists (with manufacturer's part or drawing numbers) in accordance with requirements set forth in Division 1, Article 1.04, Section 01700. The instructions shall be comprehensive, descriptive and illustrative enough to install, operate and maintain all the equipment furnished. All instruction materials shall be in the form of manufacturer's printed originals; photo-reproductions of manufacturer's originals are not acceptable.

F. Submittals of "As Built" drawings shall be in accordance with requirements set forth in Division 1, Article 1.05, Section 01700.

G. Completed and properly indexed instruction/maintenance manuals and "As-Built" drawings must be delivered to the Engineer before the completion of the Contract.

0.5 DELIVERY, STORAGE, AND HANDLING

Furnish and deliver with the equipment all special tools and equipment handling devices as recommended by the component manufacturers for the adjustment and maintenance of all equipment furnished under these specifications. Special tools are defined as tools not readily available on the open market.

0.6 QUALITY ASSURANCE

A. The design of the equipment shall provide features for the safety of personnel during operation, maintenance and repair.

B. All equipment and materials supplied by the Contractor shall be new, of recent manufacture and of highest grade as specified. They shall be resistant to moisture and corrosion to withstand their environment and operational conditions with minimum maintenance and long life.

C. Workmanship: Prepare all surfaces of equipment so that they are smooth and free of gaps, burrs, sharp edges, wrinkles, waves, blemishes, or other unsightly defects which would detract from a neat appearing finished product. Enclosing structures shall have sufficient structural reinforcements to ensure the surfaces shall remain plane and plumb, to restrain vibration, and to provide necessary strength and rigidity during shipment, installation, and operation.

D. Wherever practicable, all major electrical equipment and materials furnished under this Contract shall be the product of a single manufacturer. In the case of major items, the manufacturer shall maintain a service organization within a reasonable distance from the project which is properly staffed and equipped to make repairs as required.

E. Materials and equipment shall be the products of a manufacturer regularly engaged in the manufacture of the product and the manufacturer shall have such products of comparable capacity and function to that specified in satisfactory use for a number of years. The manufacturer of the internal equipment (switches, circuit breakers, transformer, etc.) shall also be the manufacturer of the structure, enclosure and all buss work.

F. Acceptable Manufacturers

1. Siemens
2. General Electric
3. Control Power Corporation
4. Westinghouse/Cutler-Hammer
5. ABB Power

G. The Contractor shall be responsible for the proper application and satisfactory operation of each section and component furnished under this Section of the Specification. Proposed designs and materials, which in the judgment of the Engineer would require unreasonable and/or frequent maintenance, repair, or replacement, will not be accepted.

0.7 WARRANTY

A. Substation

1. The manufacturer shall warrant all equipment furnished under this Section to be free from defects in materials and workmanship for a period of one year from the date of Authority acceptance.

PART 2 - PRODUCTS

0.1 EQUIPMENT ENVIRONMENT

A. All equipment for the _____ Substation will be installed indoors in the substation building. The Substation is located _____.

B. Substation site is located at seal level with a normal barometric pressure of 29.21 inches Hg. Outdoor temperatures in the Boston area range approximately from minus 15˚F to plus 105˚F.

C. Ventilation will be supplied to the substation buildings with filtered outside air when the inside temperature reaches 90˚F and above. Maximum expected air temperature within the building is 104˚F during hot summer days. During cool periods the temperature within the Substation will be maintained at 50˚F and above by thermostatically controlled heaters.

D. The atmosphere in Boston has a concentration of pollutants consistent with a metropolitan area with many various types of industries and heavy urban automobile and truck traffic patterns.

E. All equipment and materials supplied under this Contract shall be designed to resist dynamic earthquake loadings based on the Massachusetts State Building Code.

0.2 DESIGN REQUIREMENTS

A. General

1. The rectifiers, rectifier transformers, switchgear assemblies and auxiliary equipment specified herein and shown on Contract Plans shall function as a complete, coordinated package for normally continuous and unattended operation within the Massachusetts Bay Transportation Authority's traction power system. All components shall be sized and selected for safe, reliable operation.

2. Unless otherwise specified, all similar equipment of the same ratings shall be identical and shall be electrically and mechanically interchangeable.

3. The rectifiers and switchgear assemblies specified herein shall be designed to permit ready installation in the Substation as indicated on Contract Plans. The Contract Plans show space available and the extent of overall equipment to be installed. They also set forth certain limiting area dimensions which are to be maintained for Authority's exclusive usage and the minimum clearances as required by the Authority for safe operation. Dimensions of equipment supplied shall have approximately the same dimensions as shown on contract Plans, but under no circumstances exceed those shown on Contract Plans. DC circuit breaker units less than 23 inches wide are

not acceptable.

4. Contractor may make approved changes in the layouts shown as may be required to fit the equipment in the Substations, provided that relative positioning of equipment is not altered, limiting area dimensions and minimum clearances are maintained and that the arrangement will provide for safe operation of all equipment and that there will be no extra charges to the Authority for such modifications of the building structure and other systems affected.

5. All equipment to be installed within the Substation shall be shipped in pieces small enough to be moved into the designated location assuming all other equipment is in place. Shipping dimensions shall be such that any piece can be removed from the building in the future without dismantling other equipment. Final arrangements will be subject to the approval by the Engineer. It is required that all equipment and the AC and DC buses be designed, manufactured and shipped in such manner as to require a minimum of erection, assembly and wiring work in the field.

6. Contractor shall be responsible for the proper application and satisfactory operation of each component furnished under this Specification. Proposed designs and materials which in the judgment of the Engineer, would require unreasonable and frequent maintenance, repair or replacement shall be reason for rejection of the equipment.

7. The threads of all bolts, nuts and screws installed in the equipment and those that are used during initial assembly or normal maintenance shall be Unified Threads as per ANSI Standards B1.1 and B1.10.

B. Service Conditions

1. The 15 kV AC switchgear at _____ Traction Power Substation will be supplied through ____ feeders from Authority's 13.8 kV distribution network originating from Authority's _____ Switching Stations. The AC switchgear will supply, through step-down transformers, the rectifier and vent shaft equipment at the Substation and the Substation auxiliary loads. In addition, it will supply, via ___nominal 13.8 kV feeders each, the Authority's _____. It will also supply, at 480 volts, the Authority's existing _____ passenger station.

2. Voltage at the AC switchgear buses during light and heavy traction load periods is expected to vary from a maximum of 14.4 kV to a minimum 13.5 kV. Maximum and minimum 3-phase symmetrical short circuit capacity of the 13.8 kV system feeding the _____Substation is expected to be ___ MVA with an X/R ratio of _ and ___ MVA with an X/R ratio of _, respectively.

3. The rectifiers and DC switchgear assemblies specified herein will serve as supply for Massachusetts Bay Transportation Authority's ____ Line rapid transit system in conjunction with existing rectifier equipment installed at other locations. Loads of individual rectifiers can be expected to vary from an eight second peak near 450% of full load current rating during the four hour peak periods to a current which is a fraction of full load current during off-peak periods. High voltage spikes of either polarity from train operations and switching and lightning surges of values specified in Article 2.03.M, this Section, may be transmitted to the equipment in the Substations through the interconnecting cable system.

4. It is expected that this installation, if properly designed, will not present any harmonic or other interference problems for public telephone system and Authority's two-way communication system and signal systems. Should such problems arise, the Contractor shall give immediate and full engineering assistance to the Authority in determining proper corrective measures, including preparation of specifications for additional equipment, if any.

C. Proposed Control, Supervision and Alarm

1. General

a. The switchgear and rectifier equipment furnished by the Contractor shall be provided with protective, control and interlocking features to safeguard the various pieces of equipment and to permit both local and supervisory control as specified herein and as shown on Contract Plans. The Contract Specification and Plans indicate the basic protection and control requirements which shall be adhered to. However, the Contractor may submit alternative schemes to the Engineer for consideration and approval.

b. Not all devices referred to or shown on Contract Plans are to be supplied under this Section nor are all devices to be furnished listed herein. The listed devices have been included in the discussion hereinafter so that the Contractor can have a more complete understanding of the integration of the equipment he will supply with the overall control and supervision scheme.

c. The actual equipment is specified elsewhere in this Specification. For purposes of discussion, the following device numbers are used, which shall also be used on Contractor's schematic and wiring diagrams, arrangement drawings and bill of materials:

DEVICE NO.	FUNCTION
1	AC circuit breaker local control switch
4	Rectifier master control relay

26R	Rectifier heat sink overtemperature device-alarm
26RX	Auxiliary relay for 26R
26RH	Rectifier heat sink overtemperature device-trip
26RHX	Auxiliary relay for 26RH
27A	Station 208/120 volt auxiliary supply undervoltage relay
27B1,B2	15 kV Bus A/B differential relay DC supply undervoltage relay
27BA	Station battery charger AC input circuit undervoltage relay
27BB	Station battery charger DC output circuit undervoltage relay
27R	Rectifier lockout relay DC circuit undervoltage relay
27RA	Rectifier/transformer DC auxiliary circuit undervoltage relay
27RB	Rectifier/transformer reliable AC supply undervoltage relay
30	Annunciator
30X	Auxiliary relay for 30
32	Rectifier DC breaker directional instantaneous overcurrent trip device
32X	Auxiliary relay for 32
33	Rectifier compartment door safety interlock
43	AC breaker control mode selector switch
47A,47B	Phase sequence and undervoltage relay
47AX,47BX	Auxiliary relay for 47A, 47B
48	Rectifier incomplete sequence relay
49A	Auxiliary transformer winding overtemperature device-alarm

49TX	Transformer winding overtemperature device-alarm
49T	Rectifier transformer winding overtemperature device-alarm
49TH	Rectifier transformer winding overtemperature device-trip
50/51	Instantaneous and time overcurrent relay-phase
50N/51N	Instantaneous and time overcurrent relay-ground
51	Time overcurrent relay-phase
51C	Time overcurrent relay-cable overload
51CX	Auxiliary relay for 51C
51N	Time overcurrent relay-ground
51R	Time overcurrent relay-rectifier overload
51RX	Auxiliary Tripping relay for 51R
52B	AC bus tie circuit breaker
52F	AC feeder circuit breaker
52FX	AC auxiliary feeder circuit breaker
59	Station battery charger DC output overvoltage relay
64R	Rectifier ground relay-hot structure-trip
64RX	Rectifier ground relay-grounded structure-alarm
67	Directional overcurrent relay-phase
67N	Directional overcurrent relay-ground
72R	Rectifier DC circuit breaker
74,74X	Alarm auxiliary relays
74F, 74FX	15 kV breaker auto-trip transfer relay
83	Reliable AC control supply auto transfer switch

83A	208/120 V AC power auto transfer switch
86	Rectifier lockout relay, hand reset
86B	Bus differential lockout relay, hand reset
86X	Rectifier conditional lockout relay, electrically reset
87B	Bus differential relay
89N	Rectifier negative lead disconnect switch
95D	Annunciator flasher and bell cutoff relay
99Y	Rectifier surge protection auxiliary circuit monitoring relay
101	DC circuit breaker local control switch
102	DC feeder reclosing cycle timer
102X	Auxiliary for 102
127	Reliable AC control supply undervoltage relay
129	DC feeder load measuring contactor
143	DC breaker control mode selector switch
150F	DC feeder rate-of-rise relay
150FX	Auxiliary relay for 150F
164S	DC switchgear ground relay-hot structure-alarm
164SX	DC switchgear ground relay-grounded structure-alarm
169	DC feeder permissive setup relay
172	DC traction feeder circuit breaker
176	DC feeder instantaneous series trip device
176X	Auxiliary relay for 176
176F	DC feeder instantaneous overcurrent relay
176FX	Auxiliary timing relay for 176F

182	DC feeder load measuring relay
183	DC feeder voltage measuring transfer relay
197X	DC feeder cable energized monitoring relay
201C	Supervisory interposing relay-close
201T	Supervisory interposing relay-trip
LMR	Load measuring resistor

2. Basic Breaker Control and Interlocking.

a. The control circuits of all 15 kV incoming, outgoing, auxiliary feeder, bus tie and rectifier transformer feeder circuit breakers and all 750 volt DC traction feeder circuit breakers shall be arranged for both local control and remote control via Authority's SCADA and one-on-one supervisory systems.

b. Each of these circuit breakers shall be provided with a three position (LOCAL-OFF-SUPERVISORY) control mode selector switch, Devices 43, or 143, for transferring the circuit breaker from local control to supervisory control and from supervisory control to local control. In addition to the contacts required for the control circuit transfer, the switch shall be provided with an "a" contacts, closed in the "SUPERVISORY" open in the "LOCAL" and "OFF" position of the switch, for remote switch position indication via Authority's SCADA and one-on-one supervisory systems.

c. All control switches Devices 1, 101, shall be provided with green and red indicating lights, mounted above the switch, green at left, red at right. For equipment equipped with stored energy type operating mechanisms the red light shall be connected in series with the trip coil to monitor the trip circuit. For these breakers, a third, white indicating light shall be provided at the breaker to indicate mechanism charged condition.

d. Control switch, Device 1, and indicating lights and the control mode selector switch, Device 43, of all 15 kV incoming and outgoing feeder and bus tie circuit breakers, Devices 52F, 52FX, 52B, shall be located on the 15 kV circuit breaker control and instrument as specified in Article 2.07, this Section.

e. In addition, a control switch with indicating lights shall be provided in front of each 15 kV unit to close the circuit breaker only when the removable element is in the "TEST" position and trip the circuit breaker when the removable element is either in the “OPERATING" or "TEST" position.

f. Control circuits of 15 kV circuit breakers (except device 52T) shall be arranged to provide the following scheme of operation:

1) With the 43 switch in the "SUPERVISORY" position, local closing functions will be disabled and the circuit breaker

can be closed only via the Authority's supervisory system and only when the removable element is in the "OPERATING" position. Tripping function of the control switch at the 15 kV Breaker Control and Instrument Panel will be disabled and the circuit breaker can be tripped via the supervisory system only when the circuit breaker removable element is in the "OPERATING" position, or by the control switch at the 15 kV switchgear.

2) With the 43 switch in the "LOCAL" position, all supervisory control functions will be disabled. When the removable element is in the "OPERATING" position, the closing function of the control switch at the AC switchgear will be disabled and the circuit breaker can be closed only by the control switch at the 15 kV circuit breaker control and instrument panel and tripped by the control switches at the control panel and at the AC switchgear. When the removable element is in the "TEST" position, the closing and tripping functions of the control switch at the 15 kV circuit breaker control and instrument panel will be disabled and the circuit breaker can be closed and tripped only from its control switch at the 15 kV switchgear.

With the 43 switch in the "OFF" position, all local and supervisory control functions will be disabled, except the tripping function of the control switch at the AC switchgear, if the removable element is in the "OPERATING" position.

g. Rectifier AC (15 kV) circuit breaker, Device 52T, control switch, Device 1, and indicating lights and the control mode selector switch, Device 43, shall be located in front of the rectifier main DC circuit breaker unit, Device 72R. The rectifier main DC circuit breaker control switch, Device 101, and indicating lights shall also be located in front of the main DC circuit breaker unit. In addition, a control switch with indicating lights shall be provided in front of the rectifier 15 kV AC circuit breaker unit to close the breaker only when the removable element is in the "TEST" position and trip the circuit breaker when the removable element is either in "OPERATING" or "TEST" position. Circuit breaker control circuit shall be arranged to provide the following schemes of operation:

1) With the 43 switch in the "SUPERVISORY" position, local closing functions will be disabled and the rectifier AC and DC circuit breakers, Devices 52T and 72R, can be closed only via Authority's supervisory system and only when the respective circuit breaker removable elements are in the "OPERATING" position. Tripping function of the rectifier AC circuit breaker control switch at the DC circuit breaker unit will be disabled and the AC circuit breaker can be tripped via the supervisory system if the circuit breaker

removable element is in the "OPERATING" position, or by the control switch at the 15 kV switchgear. Rectifier DC circuit breaker can be tripped from its control switch at the DC circuit breaker unit.

2) With the 43 switch in "LOCAL" position, all supervisory functions will be disabled. When the removable elements of the rectifier AC and DC circuit breakers are in the "OPERATING" position, the closing function of the AC circuit breaker control switch at the 15 kV switchgear will be disabled and the rectifier AC circuit breaker can be closed only by its control switch at the rectifier DC circuit breaker unit. Closure of rectifier AC circuit breaker shall automatically close the rectifier DC breaker as described in Article 2.02, Paragraph C.3, this Section. With the circuit breaker removable element in the "OPERATING" position, the rectifier AC circuit breaker can be tripped by the control switches at the DC circuit breaker unit and at the 15 kV switchgear. Rectifier DC circuit breaker can be tripped from its control switch at the DC switchgear. When the rectifier AC circuit breaker removable element is in the "TEST" position, the closing and tripping function of the control switch at the DC switchgear will be disabled and the AC circuit breaker can be closed and tripped only from its control switch at the 15 kV switchgear. Similarly, the rectifier DC circuit breaker, when raced into "TEST" position, can be closed and tripped from its control switch at the DC switchgear.

3) With the 43 switch in the "OFF" position, both the local and supervisory control functions will be disabled except the tripping function of the rectifier AC circuit breaker control switch at the 15 kV switchgear and the tripping function of the DC circuit breaker control switch at the DC switchgear, provided that the circuit breaker removable element is in the "OPERATING" position.

h. DC traction feeder circuit breaker control switch, Device 101, and indicating lights and the control mode selector switch, Device 143, shall be located in front of the circuit breaker unit, Device 172. The control circuit of the circuit breaker will be provided with load measuring and automatic reclosing features described in Article 2.02, Paragraph C.4, this Section. Circuit breaker control circuit shall be arranged to provide the following scheme of operation:

1) With 143 switch in the "SUPERVISORY" position, local closing function will be disabled and the closing (load measuring) cycle can be initiated only via Authority's supervisory system and only when the circuit breaker removable element is in the "OPERATING" position.

2) With the 143 switch in the "LOCAL" position, the supervisory control function will be disabled. The closing

(load measuring) cycle can be initiated and the circuit breaker tripped only from its control switch and only when the breaker removable element is in the "OPERATING" position. With the breaker removable element in the "TEST" position, the breaker can be closed and tripped only from its control switch, initiating the load measuring cycle, but not actuating the load measuring contactor, Device 129.

3) With the 143 switch in the "OFF" position, local and supervisory closing functions and supervisory tripping functions will be disabled. The circuit breaker can be tripped by its local control switch, if the circuit breaker removable element is in the "OPERATING" position.

i. At all locations, the control mode selector switches, Devices 43, 143, shall be mounted directly above the respective breaker control switches Devices 1, 101.

j. The protective device and relay circuitry of the breakers shall not be affected by the control mode selector switch, Devices 43, 143; when actuated, these devices shall trip their respective breakers regardless of the position of the 43, 143 switch.

k. Control circuits of 15 kV circuit breakers shall be so arranged that manual trip or trip via supervisory system will not actuate circuit breaker auto trip alarm.

l. The 15 kV switchgear is normally operated with the bus tie circuit breaker, Device 52B, between the two bus sections closed.

3. Rectifier Control

a. Rectifier equipment shall be started by energizing the operating coil of the latching type master control relay, Device 4. This can be accomplished, depending on the positioning of rectifier AC circuit breaker control mode selector switch, Device 43, locally by operating the rectifier AC circuit breaker control switch, Device 1, or remotely via supervisory control through operation of the supervisory closing relay, Device 201C. The following shall prevent energization of Device 4 operating coil:

1) Operation of rectifier lockout relay, Device 86.
2) Operation of rectifier conditional lockout relay, Device 86X.
3) Operation of bus differential lockout relay, Device 86B, of the 15 kV bus section supplying the rectifier.
4) Loss of voltage of rectifier lockout relay control circuit, as detected by Device 27R.

b. Energization of Device 4 operating coil shall cause closure of the rectifier AC (15 kV) circuit breaker, Device 52T, and start the

timing cycle of the incomplete sequence relay, Device 48. Closure of breaker 52T shall energize the closing circuit of the rectifier DC breaker, Device 72R. Failure of breaker 72R to close and remain closed within the preset length of time will cause Device 48 to operate which shall result in rectifier lockout.

c. After closure of rectifier AC and DC circuit breakers, an "a" contact from each of the two breakers, connected in series, shall energize Device 4 reset coil, setting up the master control relay for the next rectifier starting operation. Device 4 reset coil shall also be energized by the operation of Device 86, provided that Device 48 has completed its timing cycle.

d. Tripping of the rectifier shall be accomplished, depending on the positioning of Device 43, locally by operating the rectifier AC breaker control switch or remotely via the supervisory control through operation of the supervisory trip relay, Device 201T.

e. Automatic shutdown of the rectifier shall be caused by operation of Devices 86, 86X, 86B, 32 and 27R. The rectifier shall be shut down by these devices regardless of the positioning of Device 43.

f. The following safety devices shall operate Device 86 and cause shutdown of the rectifier unit until Device 86 is manually reset. This type of shut-down is termed LOCKOUT. Loss of AC control power shall not cause operation of any of the following devices.

    1) Open door on rectifier diode and positive 650 volts bus compartment, Device 33.
    2) AC fault, Devices 50/51 and 50N/51N.
    3) Equipment overload detected by AC relay, Device 51R.
    4) Incomplete starting sequence, Device 48.
    5) Rectifier negative disconnect switch open, Device 89N.
    6) Operation of rectifier DC breaker directional overcurrent trip device, Device 32.

g. Following overtemperature devices shall energize Device 86X operating coil and cause shutdown of the rectifier unit until the normal condition is restored. This type of shut-down is termed CONDITIONAL LOCKOUT.

    1) Rectifier diode heat sink overtemperature second step and auxiliary power circuit undervoltage, Devices 26RHX and 27RA.
    2) Transformer winding hot spot overtemperture second step, Device 49TH.

h. Device 86X shall be automatically reset by energization of its reset coil when the equipment which caused the conditional

lockout has cooled down to safe operating temperatures.

4. DC Traction Feeder Control.

   a. All DC traction feeder circuits shall be provided with load measuring and voltage measuring equipment to prevent closing of the feeder circuit breaker, Device 172, on faulted track or faulted feeder conductors. Load and voltage measuring circuits shall be designed so that they are in service during local and supervisory control of the breakers. Circuit shall also permit the checkout of entire load and voltage measuring scheme with circuit breaker removable element in the "TEST" position, including closure of the breaker, except that the operation of Device 129 shall be blocked.

   b. Equipment associated with load and voltage measuring scheme shall include:

      1) A load measuring, or resistance measuring relay, Device 182, to measure "feeler" current through load resistor during load measuring cycle. Circuit shall be provided with means to allow load measuring only when the voltage drop in negative return circuit is below preset value (to be adjustable over a range of 10-100 volts).
      2) A voltage measuring relay, Device 183, with an adjustable range of 0-750 volts, for measuring backfeed voltage from energized track.
      3) A load measuring resistor, Device LMR, for limiting the "feeler" current to about 50 amperes.
      4) A contactor, Device 129, for connecting Device LMR across the open feeder circuit breaker, Device 172.
      5) Associated accessory devices, as required.

   c. Load measuring system shall be insensitive to variations in DC bus voltage from 750 to 300 volts and shall be arranged to determine feeder load condition automatically, whether connected to an independent track section or multi-feed section. Traction feeder circuit breaker closing shall be provided with devices which will allow the closing of the circuit breaker at a switchgear bus voltage of 450 volts or higher. Load measuring circuit and its components will be subject to the approval of the Engineer.

   d. Each DC traction feeder circuit breaker shall also be equipped with devices for automatic reclosing of the breaker, if tripped by its automatic devices, to the energized unfaulted traction feeder circuit; to the de-energized, unfaulted traction feeder circuit; and to the de-energized, unfaulted switchgear bus. The automatic reclosing of the circuit breaker shall also be initiated by unsuccessful attempt to close the breaker from its local control switch or via Authority's supervisory system. The

reclosing-load-measuring circuitry shall not be actuated if the traction feeder circuit breaker is tripped by its local control switch or via the supervisory system.

e. Reclosing cycle, once initiated, shall be continuous and shall be stopped only by successful closure of the circuit breaker or by tripping the breaker permissive setup relay, Device 169, either locally or via supervisory. A recycle timer, Device 102, shall be provided for repeated load measuring and circuit breaker closing on a 14 second cycle, including a four-second interval between the end of load measuring phase and the energization of breaker closing circuit. Circuitry shall provide for anti-pump circuit breaker operation and for verification of resetting of the load measuring devices for each cycle.

f. Cycle timer shall be of high quality, synchronous motor driven, cam-operated type, as approved by the Engineer.

g. In addition to the above specified control and protective devices, each DC traction feeder circuit breaker shall be equipped with a direct acting series bi-directional instantaneous trip device, Device 176, and protective devices capable of discriminating between inrush current of a starting train near the infeed point of the track section and a remote low-level fault. Two sets of discriminating devices shall be provided: an adjustable rate-of-rise overcurrent trip device, Device 150F, and an adjustable instantaneous bi-directional overcurrent relay, Device 176F, responding only to current magnitude, and an adjustable timing relay, Device 176FX. The rate-of-rise relay shall have the capability of being calibrated and "test" tripped throughout the entire range of the relay. The latter devices will be applied mainly to detect low level far end faults of track section.

h. Fault detection relays shall be able to detect, as a minimum, any fault current 25% above actual starting current of trains at any track section.

i. Closing and reclosing cycle for the DC traction feeder circuit breaker shall be started by energizing the operating coil of the latching type permissive setup relay, Device 169. This can be accomplished, depending on the positioning of the circuit breaker control mode selector switch Device 143, locally by operating the circuit breaker control switch, Device 101, or remotely via supervisory closing relay, Device 201C.

j. Energization of Device 169 reset coil shall cause tripping of the circuit breaker or stop the reclosing cycle in case it is in progress. This shall be accomplished locally by operating the circuit breaker control switch or remotely via the supervisory control through operation of the supervisory trip relay, Device 201T when the Device 143 is in "SUPERVISORY" position.

k. A key-operated switch shall be provided to bypass load measuring and voltage measuring devices to permit closing of traction feeder circuit breakers during an emergency, and when the Device 143 is in "LOCAL" position. Closing circuit shall be arranged to provide a ten-second interval between the rotation of the breaker control switch to "CLOSE" position and the energization of breaker closing circuit. A "LOCAL" contact of Device 143 shall be wired in series with the timer so that the timer can be actuated only when Device 143 is in the "LOCAL" position and the load measuring by-pass switch is operated.

l. It is unlikely that the DC traction feeder breakers will be called to interrupt faults greater than the fault between the breaker terminal and the negative bus when the DC switchgear is fed from three 3,000 kW rectifiers and having primary AC system characteristics as specified.

5. Supervisory Control and Indication

a. The Authority has in operation two independent supervisory systems for remote control of the AC and DC circuit breakers and for monitoring equipment and auxiliary circuits at their substations: a computer-assisted systemwide SCADA system and a one-on-one system for each of the individual traction power substations and switching stations. The master station and computer equipment of the SCADA system and the master stations of the one-on-one supervisory systems are located at the Authority's High Street Operations' Center.

b. Contractor shall furnish, install and connect a remote terminal unit (RTU) for controlling and monitoring the equipment at the traction power substation and the passenger station unit substation via Authority's SCADA system. The remote terminal unit shall be fully compatible with Authority's existing equipment and shall perform all the functions the existing system is designed for. Contractor shall make all changes and/or additions to the hardware and software of Authority's SCADA system necessary to incorporate all control, monitoring and analog functions specified for the Substation. Detailed information on the existing SCADA system and the requirements for the RTU are contained in the MBTA Specification Remote Terminal Unit for SCADA System included in Appendix O.

c. In addition, Contractor shall provide all necessary master and remote terminal equipment for the second, one-on-one, supervisory system, controlling and monitoring only critical functions as required by State Law for operation of unmanned substations. The equipment shall be provided in full accordance with MBTA Specification P-139A, Supervisory Control and Indication, included in Appendix N. The RTU will be located in the Substation. The master terminal unit (MTU) will be located

in High Street Operations' Center or South Boston Switching Station.

d. Remote terminal units of SCADA and the master and remote terminal unit of the one-on-one supervisory system shall each contain a power source and a backup power source consisting of a nickel-cadmium storage battery, battery charger, and necessary inverter equipment. Equipment shall be designed for operation on 120 volt, 60 Hz. The RTU's shall be designed to handle all the control, indication and analog inputs specified for the equipment, and shall be provided with a minimum of 20% spare points for future use.

e. Contract shall furnish, install and connect all interposing relays, Devices 210C, 201T, for proper interfacing of the breaker control circuits with the supervisory remote terminal equipment, and provide a normally open contact from each supervisory-controlled circuit breaker for remote breaker contact position indication. Contractor shall also provide all contacts, relays and devices necessary for remote monitoring of below listed equipment and circuits. The interposing relays shall be supplied from the 125-volt DC control bus of the switchgear through a set of fuses. The load side of positive fuse, one side of the interposing relay coil and all supervised status contact devices shall be wired to outgoing wiring terminal blocks at switchgear and rectifier equipment. These circuits shall be extended to an interface terminal box near the supervisory equipment cabinets. The interface terminal box and wiring between it and the equipment shall be furnished and installed by the Contractor. Wiring between the interface terminal box and the supervisory equipment cabinets will also be provided by the Contractor. The interface terminal box shall be provided in accordance with Article 2.11.B, this Section.

f. Contractor shall provide two electrically independent contracts for each status indication function specified: one for SCADA, the second for one-on-one supervisory equipment. Provisions shall be made to extend momentary type contact closure to one second, minimum, for proper processing of the signal by the supervisory equipment. Additional electrically independent status indication contacts shall be provided for all other indication and alarm functions.

g. The supervisory communication wiring to Authority's central equipment at High Street will be furnished, installed and connected by others. The surge protection devices for the communication lines at the Substations and at High Street shall be furnished, installed and connected by the Contractor.

h. The following equipment at the Substation shall be provided with devices for remote close-trip control and indication (a

normally open contact of circuit breaker) via Authority's SCADA system and one-on-one supervisory system:

1) Incoming and outgoing 15 kV feeder circuit breakers, Device 2F.
2) 15 kV auxiliary feeder circuit breakers, Device 52FX.
3) 15 kV bus tie circuit breaker, Device 52B.
4) Rectifier 15 kV circuit breakers, Device 52T. The interposing relays, Device 201C, 201T shall start the rectifier units by energizing the latching type master control relay, Device 4 and by tripping Device 52T as described in Article 2.02.C, Paragraph 3, this Section. A normally open contact of Device 52T shall be provided for remote indication.
5) 750 volt DC traction feeder circuit breakers, Device 172. The interposing relays, Devices 201C, 201T, shall start the circuit breaker closing cycle and trip the breaker by energizing and resetting the latching type permissive setup relay, Device 169, as described in Article 2.02.C, Paragraph 4, this Section. A normally open contact of Device 172 shall be provided for remote indication.

i. Circuits and devices listed below shall be provided with monitoring contacts for remote indication via Authority's SCADA system and the one-on-one supervisory system. Additional status indicating functions are specified in Sections 15600, 16312 and 16720.

1) Position of control mode selector switches of all supervisory-controlled breakers, Devices 43, 143
2) Rectifier DC circuit breaker, Device 72R
3) DC traction feeder circuit breaker load measuring cycle in progress, Device 102 or 102X
4) Rectifier lockout relay, Device 86
5) 15 kV bus differential lockout relay, Device 86B
6) 15 kV bus undervoltage, Device 47AX, 47BX
7) Transfer of 120/208 volt, 60 Hz station auxiliary supply to standby source, Device 83A
8) Annunciator, Device 30, auxiliary relay, Device 30X
9) DC traction feeder circuit breaker trip by its rate-of-rise relay, Device 150FXDC traction feeder circuit breaker trip by its instantaneous series overcurrent trip unit, Device 176X
10) DC traction feeder circuit breaker trips by its overcurrent relay auxiliary, Device 176FX
11) DC traction feeder cable energized indication, Device 197X
12) 13.8 kV feeder cable overload, Device 51CX
13) Station battery trouble

6. Telemetering Requirements

a. The Contractor shall furnish, install and connect all measuring devices, transducers, amplifiers, totalizers, resistors and all other devices necessary for providing proper inputs to Authority's SCADA system for remote telemetering of below listed quantities. The transducers shall have the characteristics specified in Article 1.11, Section 16203. The telemetering signal circuits shall be wired to outgoing wiring terminal blocks at the switchgear. The circuits shall be extended by the Contractor through the interface terminal box, as described in Article 2.02.C. Paragraph 5, this Section for supervisory control and indication circuits, to the supervisory equipment.

b. The following power circuits shall be provided with devices for telemetering:

1) Voltage of each 15 kV switchgear bus section (signal from voltage transducers).
2) Phase B current of each 13.8 kV incoming and outgoing feeder (signal from current transducers).
3) Voltage of 750 volt DC switchgear bus (signal from voltage transducer).
4) Kilowatt hours and kilowatt-hour demand of each 13.8 kV outgoing feeder, rectifier transformer feeder and 13.8 kV auxiliary feeders (input from watt-hour demand meter pulse initiators).
5) DC traction feeder current (signal from feeder shunt through isolation amplifier).
6) Rectifier DC output current (signal from rectifier shunt through isolation amplifier).
7) Negative drainage circuit current (signal from negative drainage circuit shunt through isolation amplifier).

7. Ground Detection of Rectifier and DC switchgear

a. Rectifiers and DC switchgear shall be installed so that their enclosures are insulated from ground and substation building structure. For each rectifier unit and the DC switchgear lineup, the Contractor shall provide a set of ground detection equipment, including a high resistance ground relay, Device 64R for rectifier, 164S for DC switchgear, a semi-conductor rectifier for auxiliary DC power supply (copper oxide or selenium rectifiers are not acceptable), a relay, Devices 64RX, 164SX, for checking the continuity of Devices 64R, 164S detecting circuit and associated devices, for continuous monitoring of the insulation of the equipment enclosure from station ground and negative bus and from rectifier or DC switchgear positive bus and components operated at bus potential.

b. Ground detection equipment shall be rated for operation on 120 volt 60 Hz, supplied from the reliable AC source at the DC switchgear. The ground relay, monitoring relay and associated

circuit components shall be rated for 750 volt DC service, minimum.

c. For the rectifier units, the Device 64R shall be set to pick up at 50 volts positive potential of the high resistance grounded rectifier structure or enclosure and shall cause lockout and de-energization of the rectifier as described in Article 2.02.C, Paragraph 3, this Section, also to provide local alarm on Device 30 and remote indication via supervisory. An electrical contact of a transformer secondary lead to the ungrounded structure or enclosure shall also cause rectifier lockout. Device 64RX shall provide local alarm on Device 30 and remote indication, via supervisory, in the event of loss of AC supply, opening of the ground detection circuit or an electrical contact of the ungrounded structure to ground or the negative bus. Device 64RX alarm and remote indication circuits shall be provided with two-second time delay to override momentary dips in the AC power supply.

d. For the DC switchgear, the Device 164S shall be set to pick up at 50 volts positive potential of the high resistance grounded switchgear structure or enclosure and shall provide local alarm on Device 30 and remote indication via supervisory. Device 164SX shall provide local alarm and remote indication, via supervisory, in the event of opening of the ground detection circuit or an electrical contact of the ungrounded structure to ground or negative bus. Device 164S shall not be activated during normal fault clearing operation of rectifier AC circuit breaker. Device 164SX alarm and remote indication circuits shall be provided with two-second time delay to override momentary dips in the AC power supply.

e. For the DC switchgear assembly, the Contractor shall provide a 120 volt AC alarm bell, supplied from the reliable 120 volt AC control bus of the DC switchgear through a set of fuses, energized by operation of Device 164S. The bell shall be wired through Substation door switch, to prevent operation during substation unattended periods. An adjustable timer shall be provided to limit the bell operation. In addition, the Contractor shall provide for the DC switchgear assembly a flashing illuminated sign bearing the legend "SWITCHGEAR FRAME ALIVE", supplied from the 125 volt DC control bus of the DC switchgear through a set of fuses, also energized by operation of Device 164S. The sign shall be prominently mounted on the switchgear assembly. The alarm bell circuit shall be provided with a relay to energize the warning sign. The warning sign shall also be energized in the event of the 120 volt AC alarm supply failure. The alarm devices and the warning sign shall be insulated from switchgear enclosure for a minimum of 1,000 volts DC.

f. All ground detection alarm, supervisory and auxiliary circuits requiring external connections shall be wired to outgoing wiring terminal blocks for connection to field wiring.

8. Local Alarm

a. Each of the following trouble conditions of substation equipment and circuits shall be provided with an alarm point on local annunciator:

1) On Rectifier No. 1 annunciator

ACTUATING ALARM FUNCTION	DEVICE
Rectifier Lockout	86
Rectifier conditional lockout	86X
Rectifier LO circuit DC supply failure	27R
Rectifier/transformer DC auxiliary supply failure	27RA
Rectifier/transformer AC reliable supply failure	27RB
Rectifier surge protection circuit failure	99Y
Rectifier heat sink overtemperature or AC supply failure	26RX
Rectifier structure grounded	64RX
Rectifier structure hot	64R
Rectifier incomplete start	48
Rectifier door open	33X
Rectifier transformer winding overtemperature	49TX
Negative lead disconnect switch open	89N
Main DC breaker reverse current trip	32X
DC switchgear structure grounded	164SX
DC switchgear structure hot	164S
13.8 kV Bus A and/or B different lockout	86B1,86B2
13.8 kV Bus A and/or B undervoltage PT secondary circuit trouble	47AX, 47BX
13.8 feeder breaker autotrip	74F,74FX
13.8 kV feeder cable overload	51CX
13.8 kV Bus A and/or B differential circuit DC supply failure	27B1, 27B3
Unit substation TPS/VSF trouble	49A, etc.
Unit substation TPS/AUX trouble	49A, etc.
Annunciator DC supply failure	74

2) On Rectifier No. 2 annunciator:

Rectifier lockout	86
Rectifier conditional lockout	86X
Rectifier LO circuit DC supply failure	27R
Rectifier/transformer DC auxiliary supply failure	27RA
Rectifier/transformer AC reliable supply failure	27RB

Rectifier surge protection circuit failure	99Y
Rectifier heat sink overtemperature or AC supply failure	26RX
Rectifier structure grounded	64RX
Rectifier structure hot	64R
Rectifier incomplete start	48
Rectifier door open	33X
Rectifier transformer winding overtemperature	49TX
Negative lead disconnect switch open	89N
Main DC breaker reverse current trip	32X
Reliable 115 V AC supply failure	127
Reliable 115 V AC supply transfer to invertor	83
208/120 V AC power supply failure	27A
208/120 V AC power supply transfer to standby	83A
Station battery trouble	59,27BA,27BB
Filters clogged	FILTER DIFF SW
Fire	FIRE ALARM PNL
Battery room vent system failure	AIR FLOW SW
Annunciator DC supply failure	74

D. Protective Device Coordination

1. General

   a. The Contractor shall furnish protective devices in the switchgear and power rectifier equipment as listed elsewhere in this Section, or as may be required, to provide reliable coordinated protection for the system. All such devices shall be adjustable and shall be factory calibrated to provide the general scheme of protection outlined below. The Contractor shall submit to the Engineer, for approval, the recommended settings of the protective devices, also show the settings on log-log paper for graphic proof of the required device coordination based on requirements specified in Article 1.04, Paragraph C.7, this Section.

2. Protective Devices at AC Switchgear

   a. Rectifier AC feeder instantaneous overcurrent relay, Device 50, shall trip rectifier AC (15 kV) circuit breaker, Device 52T, for 13.8 kV circuit and rectifier transformer faults. Pickup shall be set 125% above the maximum inrush current of the transformer-rectifier package, or 125% above bolted secondary fault at the DC traction feeder load terminal, whichever is greater.

   b. Rectifier AC feeder time overcurrent relay, Device 51, shall trip the rectifier AC and DC circuit breakers for rectifier transformer secondary circuit faults and DC switchgear bus faults. Pickup shall be set to coordinate with the reverse current trip, Device 32, of the rectifier DC circuit breaker, Device 72R of the second rectifier operating in parallel and with the protective devices of

DC traction feeder circuit breaker**s**, Device 172. In addition, the setting of Device 51 shall be selective with the individual series fuses of the diodes so that the diodes fuses will not blow on an external fault.

c. Rectifier AC feeder time overcurrent relay, Device 51R, shall trip the rectifier AC circuit breaker for rectifier overload. Relay shall be set to pick up in approximately 60 seconds at 300% of rectifier full load current. The setting shall also allow two hour operation of the rectifier at 150% of rated full load and at 450% full load current for 15 seconds. The setting of Device 51R shall afford selectivity with the series diode fuses and with the protective devices of DC traction feeder circuit breakers.

d. An auto-trip of rectifier AC circuit breaker shall sequentially trip the rectifier DC circuit breaker, Device 72R.

3. Protective Devices at Rectifier Transformer.

Rectifier transformer winding overtemperature device, Device 49TH, shall be set to trip the rectifier conditional lockout relay, Device 86X, following operation of the rectifier at 160% of full load for approximately two hours at the design temperature listed in Article 2.04**,** this Section.

4. Protective Devices at Rectifier.

a. Each diode shall be protected with an individual series current limiting fuse selected to blow for diode shorting failure only

b. Rectifier heat sink overtemperature devices, Device 26RH, shall be set to trip the rectifier conditional lockout relay, Device 86X, on heat sink high temperature that would result in failure of rectifier elements and fuses, before devices at AC and DC switchgear could operate.

5. Protective Devices at DC Switchgear

a. Rectifier DC circuit breaker reverse current device, Device 32, shall instantaneously trip the rectifier DC and AC circuit breakers, Devices 72R, 52T, at no more than 20% of the rectifier rated current. *Normally this setting is made at 10% of the rectifier rated current*. Coordination of protective devices shall prevent tripping of AC circuit breakers of any rectifier operating in parallel.

b. DC traction feeder instantaneous series overcurrent bi-directional magnetic trip device, Device 176, shall be set to trip the feeder breaker, Device 172, on heavy overcurrent or short circuit. Polarized bi-directional rate-of-rise overcurrent trip device, Device 150F, and the bi-directional instantaneous

overcurrent relay, Device 176F, and its timing relay Device 176FX, shall have operating characteristics and adjustable ranges such as to trip for remote short circuits on the track and discriminate against tripping for inrush on starting of nearby trains. The settings of all DC feeder circuit breaker protective devices shall be coordinated with the devices of rectifier AC (15 kV) circuit breaker so that DC traction feeder faults will not cause the tripping of the AC circuit breaker. Load measuring and automatic reclosing features of DC traction feeder circuit breakers will cause automatic reclosure as soon as the condition that caused tripping is corrected.

0.3 15 kV AC SWITCHGEAR ASSEMBLY

A. General

1. The switchgear assembly shall consist of indoor metal-clad self supporting units rated for operation on nominal 13.8 kV, three-phase, three wire, 60 Hz grounded neutral service. The switchgear shall be arranged to accommodate future extensions from each end of the switchgear assembly.

2. Contractor shall submit within 30 days before the Design Conference, for Engineer's approval, design calculations or test data defining the amplitudes of transient overvoltages produced by the vacuum circuit breaker during switching operations. The data submitted shall cover switching transients caused by prestriking, current chopping, virtual chopping and repetitive reignition phenomena for the following switching operations:

    a. On and off switching of the transformer and rectifier package at no load, rated load and 150% of rated load. Circuit from the circuit breaker to rectifier transformer high voltage terminals shall be assumed to consist of 50 feet of 3-single conductor, No. 4/0 AWG, 15 kV, solid insulated, shielded cables in a steel conduit.
    b. On and off switching of a 1,000 kVA, three-phase 13.8 kV 480/277 volt conventional dry type transformer, with standard impedance, at no load (magnetizing current only) and at rated load. Circuit from circuit breaker to transformer high voltage terminals shall be assembled to consist of 50 feet of 3-single conductor, No. 4/0 AWG, 15 kV, solid insulated, shielded cables in a steel conduit.

3. If the data submitted at the Design Conference or obtained during the rectifier package test, specified in Article 3.03.C, this Section, indicate a transient peak surge voltage in excess of 50 kV at circuit breaker or transformer terminals, Contractor shall furnish and install surge suppressors at the line side terminals of each of the four circuit breakers feeding the rectifier and unit substation transformers in the Substation. Surge suppressor equipment will be subject to the

approval by the Engineer. Distribution class lightning arresters are not acceptable as surge suppressors.

B. Ratings

1. The switchgear assemblies shall be rated as follows:

Nominal voltage	13.8 kV
Maximum voltage	15.0 kV
Frequency	60 Hz
Insulation Level, 60 Hz withstand	36 kV
Insulation Level, Impulse withstand	95 kV
Main bus continuous current	1200 amp
Short circuit duty	As listed in Article 2.01.E, this Section

C. Switchgear Assembly

1. The metal-clad switchgear assembly shall consist of rigid self-supporting and self contained, electrically welded steel structure units. Individual units shall be enclosed with not less than 12 gauge formed steel sheets. Each unit shall be bolted to each other to form a continuous, free standing switchgear assembly.

2. The switchgear dimensions shall be of sufficient depth and height to allow the racking-in of the ground and test device with the front door of the circuit breaker compartment closed, as specified in Article 2.03.F, this Section. The depth and height of the switchgear shall be increased, as required, if manufacturer's standard switchgear does not allow the specified operation of the ground and test device. Ground and test device clearances will not be compromised due to switchgear cubicle size.

3. Hinged doors shall be provided with each unit, located both on the rear and on the front of the switchgear assembly, for access to breakers, instruments and terminal blocks, relays, meters, control devices, and buses. Instruments and relays mounted on the front door and not barriered or compartmented from the circuit breakers are acceptable. Doors shall be formed of sheet steel and shall be properly reinforced against distortions by suitable flanges and stiffening members. Hinges shall be heavy duty of a type approved by the Engineer. Full height doors shall be securely fastened in the closed position with a minimum of three latches easily opened without the use of tools. For doors less than the full height of the switchgear, a minimum of two latches will be acceptable.

4. Front doors shall be provided with three-position automatic self-stopping mechanism with the first automatic stop at 45˚, the second at 90˚ and the third at 120˚. Manual defeating feature of the mechanism shall be provided for moving the door from one position to the other. At each stop, the door shall be held securely in the open

position. With the front door of any compartment open at 90˚ position, it shall not prevent the adjacent compartment door from being opened and its breaker completely removed from its housing. Rear doors shall be provided with stops to hold them securely open at 90˚ in a manner to allow the opening of the doors of adjacent cubicles.

5. The front door of each circuit breaker housing shall be provided with a properly sized opening, covered with a sliding door, for the passage of the pushbutton station and the control cable of the ground and test device specified in Article 2.03.F, Paragraph 7, this Section.

6. The circuit breakers, buses, instrument transformers, incoming and outgoing cables, instruments, and control devices in each switchgear unit shall be isolated within separate grounded compartments formed by sheet steel barriers. All compartments shall be sufficiently gas tight to assure that no ionized gas will pass from one compartment to another. Each compartment shall be provided with a separate hinged door or a removable bolted-on cover with handles for gripping for servicing, without exposing circuits in adjacent compartments. All unused holes and openings between compartments shall be sealed.

7. Vent openings on top of switchgear shall be installed through vertical surfaces to prevent the entry of foreign objects. Openings shall be arranged so that hot gases or other materials cannot be discharged through them in a manner which might be injurious to operating personnel. Grills located on top of switchgear shall be reinforced so that they will not be damaged if stepped on.

8. Each circuit breaker unit shall be provided with protective shutters which are forced to close and cover live high voltage terminals as the removable element of breaker is racked out of the cubicle. If the shutters are made of steel, the clear distance from the shutter plate to any uninsulated primary circuit component on the circuit breaker shall not be less than seven inches at any point during the circuit breaker and the ground and test devices racked-in and withdrawal operation.

9. Primary circuit portholes shall be identified with permanently attached nameplates engraved "BUS" and "CABLE" at each circuit breaker housing.

10. Finish of inside and outside of the switchgear assembly shall be in accordance with Article 1.16, Section 16203.

D. Buses

1. Main buses and bus taps in breaker housing and breaker removable element shall be in accordance with Article 1.06, Section 16203, and as follows:

a. Main buses and bus taps in the breaker housing and on the breaker removable element shall be fully insulated with flame-retardant, track resistant molded insulation rated for 15 kV, or by other methods as approved by the Engineer. The insulating material shall not be construed as flame-retardant unless it is capable of meeting the requirements of ANSI C37.20. Bus conductors shall be supported and braced to withstand short circuit stresses at least as great as those for which the circuit breakers are designed for. Insulated supports of main bus shall be arranged to form a gas-tight barrier which shall isolate each unit from the adjacent unit. Phase-to-phase and phase-to-enclosure distances shall be based on in-air clearances without the benefit of the insulation applied to buses.

2. Two ground buses shall be provided within the switchgear assembly in accordance with the following:

a. A continuous copper ground bus, 2 inches by 1/4 inch or larger, shall extend throughout the entire length of the switchgear assembly. Each unit shall be grounded directly to this bus. The frame of each circuit breaker shall be grounded through a rugged contact shoe at all times, except when the primary disconnecting devices are separated by a safe distance. A bolted type terminal lug, with a two-bolt tongue, in accordance with Article 1.07, Section 16203, shall be provided at each end of ground bus for field connection to the station ground. The lugs shall be suitable for stranded copper ground cable within the range of No. 4/0 AWG through 500 kcmil.

b. A continuous copper ground bus, 1-1/2 inches by 1/4 inch, insulated from the switchgear frame, shall be provided for bonding the potheads and the shields, and sheaths of the incoming and outgoing 13,800 volt cables. The ground bus shall be installed near the rear door, at a maximum of six inches from floor, and shall extend throughout the entire length of the switchgear assembly. A bolted type terminal lug, with a tow bolt tongue, in accordance with Article 1.07, Section 16203, suitable for stranded copper cable within the range of No. 4 through No. 4/0 AWG, shall be provided at each end of the bus for field connection to the negative equalizer bus and drainage board.

c. Ground bus splices shall be made with a minimum of four bolts, two bolts on each side of the splice plate.

E. Power Circuit Breakers

1. Power circuit breakers shall be of the nominal 13.8 kV class, three pole, employing vacuum interrupters, draw-out type, designed for operation on 60 Hz and rated on symmetrical current basis, in accordance with ANSI C37.06 as follows:

Nominal three-phase MVA	750
Rated continuous current	1200 A
Rated maximum voltage	15.0 kV
Rated voltage range factor (K)	1.3
Rated withstand test voltage:	
Low Frequency (rms)	36 kV
Impulse, crest	95 kV
Rated short circuit current at maximum voltage (rms)	28 kA
Maximum symmetrical interrupting capability (rms)	36 kA
Three-second current carrying capability (rms)	36 kA
Closing and latching capability (rms)	58 kA

2. The specified interrupting duty of breakers is based on conditions imposed by two unit operations with a 15 second interval between operations. Each unit operation shall consist of closing the breaker, followed immediately by its opening without intentional delay. At the end of the second operation, the breaker shall be substantially in the same mechanical and electrical condition as before operation.

3. Operating mechanisms shall be of the stored energy type, suitable for operation from a 125-volt DC supply, and electrically and mechanically trip free. Operating circuits shall successfully close the breaker over a voltage range of 90 volts to 140 volts and trip the breaker over a voltage range of 70 volts to 140 volts. The breakers shall be designed so that they may be tripped manually in an emergency. A removable handle shall be provided for manual closing of the breaker for maintenance and adjustment. An operating mechanism shall be provided with a mechanism charging motor cut-off switch mounted on the breaker removable element and a mechanical breaker contact position indicator visible from the front when the breaker is inserted in its housing.

4. The stabs of the removable element and the bus will be insulated to the same requirement as specified in Article 2.03.D, Paragraph 1.a., this Section.

5. In addition to auxiliary switches required for control, interlock, indication, and alarm circuits, provide each circuit breaker with a minimum of four "a" and four "b" spare auxiliary switch contacts wired to outgoing wiring terminal block for Authority's use. Auxiliary switches mounted on stationary structures are acceptable.

6. Auxiliary switches and breaker control circuit wiring connected through the secondary disconnecting devices shall be operable when breaker is racked to the test position so that the breaker can be closed and tripped, electrically or mechanically, with primary disconnecting devices open.

7. Normally closed auxiliary switches mounted on the removable element and used for interlocking shall be shunted with truck operated cell switches to permit operation of interlocked equipment

when breaker is in the withdrawn position. A minimum of two "a" and two "b" spare cell switch contracts shall be provided, wired to outgoing wiring terminal block for Authority's use.

8. Each circuit breaker shall be mounted on a mobile steel frame equipped with main and secondary circuit disconnecting devices. The frame shall be permanently attached to the circuit breaker and shall be equipped with wheels for rolling the circuit breaker on the floor of the Substation. *All AC circuit breakers are required to be a "direct roll-in" design which allows moving the breaker over the concrete substation floor into the switchgear unit, and vice versa, without the need for portable ramps or wedges*. A four-digit register type operations counter shall be mounted on the removable element of each circuit breaker.

9. Circuit breakers of same rating shall be mechanically and electrically interchangeable.

10. The primary disconnecting devices shall consist of self-aligned assemblies. The female contacts shall be constructed of bridging segments of fatigue-resistant zirconium copper alloy with silver tungsten arching tips or similar approved high quality material, designed to ensure high-pressure contact and guaranteed not to distort or fail under the mechanical stresses and heating due to duties specified for circuit breakers. All contact surfaces shall be heavily silver plated.

11. Secondary disconnecting devices shall provide connections for the control circuits and interlocks between the removable element and the housing. The devices shall be accurately located and securely mounted to maintain alignment.

12. Each switchgear unit housing a circuit breaker shall be equipped with a cranking device for moving the removable breaker element to and from it operating position. The cranking device shall be permanently attached to either the stationary housing or to the removable breaker unit. Suitable guide rails which prevent misalignment shall be provided for centering the breaker in proper position when inserting or withdrawing the removable element. A positive stop shall be provided for the test position and fully disconnected position. Provisions shall be made for padlocking the removable element in the operating and fully disconnected positions. Provisions shall be made to the front of the cubicle's hinged door to provide a sliding shutter to cover and aperture utilized for the cranking device. The circuit breaker shall be able to be racked or cranked from the "test" position to the "operating" position with the cubicle unit door closed.

13. Front ends of guide rails shall be flared and the bottom plate of the enclosure within the guide rails beveled to facilitate the lining-up and insertion of the circuit breaker removable element.

14. Mechanical interlocks shall be provided on each circuit breaker to prevent the withdrawal of the removable element when the breaker is in the closed position and to prevent the insertion of a closed breaker from the test to the operating position. The interlocks shall also discharge the spring of the stored energy operating mechanism before the breaker removable element can be fully withdrawn from its housing.

15. The racking-in mechanism shall be manually operated, threaded shaft type employing a removable crank. Lever type rack-in mechanism will not be acceptable.

16. Provide one spare AC circuit breaker that is compatible with all 15 kV AC cubicles for this project.

F. Ground and Test Device

1. Ground and test devices shall be provided to ground the primary circuits of the switchgear during maintenance work and to provide access to high voltage circuits for high potential testing and phase checking. The ground and test device shall be a mobile draw-out element that can be inserted into a switchgear housing in place of a circuit breaker. The ground and test device shall be constructed in compliance with all mechanical features specified for the circuit breaker removable element, *and shall be a "direct roll-in" design which allows moving the device over the concrete substation floor into the switchgear unit, and vice versa, without the need for portable ramps or wedges*.

2. The ground and test device shall be designed so that it can be racked from the "test" to "operating" position with the breaker compartment door closed. Clearly indexed positive stops shall be provided for the operating, test and disconnected position.

3. The ground and test device shall be provided with three primary disconnecting devices for connection to the feeder cable terminals, and with three uninstalled primary disconnecting devices for connection to the switchgear bus. The ground and test device will be accepted with all six primary disconnecting devices installed, provided that those for connection to switchgear bus can be readily removable in the field. The ground and test device shall be provided with a sliding contact assembly, of appropriate ampacity, for connecting to switchgear ground bus; a 15 kV three pole, two position, manually operated air break primary selector switch; and a stored energy operated air break ground switch capable of closing and latching against a live circuit. Ground and test device employing vacuum break interrupter as the ground switch will not be acceptable. Windows of non-shatterable material shall be provided for observation of ground switch contact position when the grounding and testing device is racked into the switchgear. Windows on the top and side panels of transparent insulating, non-shatterable material

shall also be provided for viewing the position of the selector switch, the ground switch, the bus work and the primary circuit cable from the buses at the primary circuit disconnect devices to the test ports.

4. Test port cables shall be firmly supported and installed with phase-to-phase distances based on in-air clearances without the benefit of the cable insulation, unless barriers of insulating material are installed to separate the phases.

5. The stabs of the movable element and the bus will be insulated to the same requirement as specified in Article 2.03.D, Paragraph 1.a., this Section.

6. Interlocks shall be provided so that the primary circuit selector switch can be operated only while the ground and test device is outside the switchgear. Mechanical interlocks shall be provided to permit the insertion and removal of the ground and test device only when the ground switch is open. A mechanical interlock shall be bolted to the selector switch operator to prevent positioning of the ground switch from cable side to bus side unless the interlock is removed. Means for padlocking the ground switch in open and closed positions shall be provided.

7. The ground and test device shall have the same voltage, three second current carrying capability, and closing and latching capability as specified in Article 2.03.E., this Section, for the circuit breakers. The ground switch control circuit shall be rated for operation on 125 volts DC. The control circuit shall be wired to the secondary disconnecting devices matching those furnished with the circuit breaker removable elements. A 20 foot long control cable, with a pushbutton station at the end, shall be provided for electrically closing and tripping the ground switch. A timing relay, adjustable between 5 and 50 seconds, shall be provided for the ground switch closing circuit. Interlocks shall be provided to permit the closure of the ground switch only when the ground and test device is racked into the "operating" position. A manual handle shall be provided for closing the ground switch when the ground and test device is inserted in the breaker housing.

8. Arrangements shall be made to prevent the operation of the structure-mounted circuit breaker auxiliary switches during the racking-in and withdrawal operation of the ground and test device.

9. Primary circuit test terminals shall be recessed, and the access ports furnished with automatic shutters. Contractor shall provide the ground and test device with a set of high voltage test probes for applying an external test voltage to the incoming feeder cable or switchgear bus. These test probes shall be self-powered, requiring no auxiliary supply for operation. Battery-operated test probes are not acceptable. Connector detail requirements will be furnished by the Engineer.

10. The primary disconnect devices, test port openings and the selector switch positions shall be identified with permanently attached nameplates engraved "BUS" and "CABLE". Similarly, all references to the primary circuit positions on the schematic and wiring diagrams and in the operating instructions shall be "BUS and "CABLE".

11. A nameplate, depicting the primary circuit in single line form shall be permanently attached to the front or side of the ground and test device.

12. The ground and test device will be used for hi-pot proof testing the external 15 kV cables. A DC test source up to 45 kV will be applied to the cable through the ground and test device for five minutes while the ground switch is open.

13. The construction details, list of components, single line and schematic diagrams and operating procedure of the ground and test device shall be submitted to the Engineer for approval.

G. Instrument Transformers

1. Instrument transformers shall be of the dry type. Transformers and associated wiring shall have mechanical strength and thermal rating commensurate with rating of associated equipment.

2. Voltage transformers for relaying and indication shall have ratios as specified in Article 2.03.P, this Section, a minimum thermal rating of 1,000 volt amperes with 55˚C rise above a room ambient of 40˚C, and an accuracy of 0.3 with ANSI standard W, X, and Y burdens, 0.6 with Z burdens, and 1.2 with ZZ burdens. Voltage transformers shall be equipped with current limiting primary fuses and shall be mounted on draw-out or tilt-out carriages. The front of the carriages shall be designed to close the section when the transformers are in the operating position. Primary contacts for the dew-out feature shall be of a design which will ensure continuous positive contact pressure. Carriages shall be of sufficiently rigid design to maintain proper alignment of the primary contacts. Visible grounding devices shall be provided to ensure that the draw-out carriage mounted voltage transformer primary terminals are grounded when the carriage is withdrawn. A flexible braided strap shall be provided for bonding the drawout carriage to the switchgear enclosure.

3. All voltage transformer primary circuit connections from bus or line side terminals of circuit breakers to the primary fuses shall be of No. 2/0 AWG, minimum, copper wire, fully insulated for 15 kV. Connections from the fuses to the high voltage terminals of the transformers shall be No. 6 AWG minimum, copper wire, fully insulated for 15 kV. Phase-to-phase and phase-to-enclosure distances shall be based on in-air clearances, assuming bare conductors.

4. Ungrounded conductors of voltage transformer secondary circuits

shall be fused. Fuses shall be of the dual element, cartridge type, rated 20 amperes, 250 volts, mounted in barrier-type, porcelain base fuse holders.

5. Provisions shall be made for storing a set of three primary current-limiting fuses in each voltage transformer compartment.

6. Current transformers for relaying and indication shall be of the window-type, with the ratio and accuracy class specified in Article 2.03.P, this Section, rated 600 volts, minimum, and designed to withstand full wave impulse test of 10 kV. The primary circuit busbar shall be located at the center of the current transformer window, firmly supported, and fully insulated for 15 kV. The installation of current transformers shall withstand the dielectric and impulse tests specified for the switchgear assembly.

7. Frames and cases of the current and voltage transformers, the secondaries of the current transformers, and the common secondary conductor of the voltage transformers shall be grounded to the switchgear ground bus. Grounding of the voltage transformers and the carriage to the switchgear ground bus shall be made with an extra flexible grounding cable. All grounding conductors shall be made as short as possible, not grouped with other conductors, and shall be No. 6 AWG copper wire or larger. Ground wires shall be continuous without splices or intermediate connections. The current transformer ground wire shall be separate from the voltage transformer ground wire. The case ground wires shall be separate from the ground connections to the instrument transformer secondary wiring.

H. Primary Circuit Terminations

1. Switchgear shall be arranged for top or bottom entrance of incoming and outgoing feeder cables, as shown on Contract Plans. The Contractor shall provide necessary terminations for power cables connecting to the breaker load side terminals. Potheads shall be provided for terminating 15 kV paper-insulated, lead jacketed cables. Solid insulated cables shall have stress cone type terminations. Buses and current transformers in the cable entrance compartments of the switchgear shall be arranged to provide ample space for 15 kV cable termination by pothead or stress cones.

2. Potheads shall be indoor, three conductor, soldered-joint type, suitable for terminating three conductor, 15 kV, shielded, paper-insulated**,** lead-covered cable. Potheads shall have cast bodies of no-ferrous material complete with uncut wiping sleeve. Insulators shall be of high strength wet-process porcelain, rated 15 kV, and designed to withstand an impulse test of 110 kV. Potheads shall be mounted on split adapter plates to facilitate removal. Removable, flexible braided copper connectors shall be provided for connecting the potheads to circuit breaker line side terminals.

3. The Contractor shall supply and ship with the switchgear assembly, an adequate quantity of filling compound for potheads. The filling compound shall be of high dielectric oil-insoluble non-migrating type.

4. Pothead supports shall be insulated from switchgear frame to prevent circulation of current between cable sheath and switchgear structure. The body of potheads shall be connected to the insulated ground bus specified in Article 2.03, Paragraph D.2, this Section, by means of an insulated, braided flexible copper connector.

5. The Contractor shall provide heavy-duty, bolted type terminal lugs for power cables for which potheads are not specified, in accordance with Article 1.07, Section 16203. For 350 kcmil and smaller cables, the terminal lugs shall have two-bolt tongues; for 500 kcmil and larger cables, four-bolt tongues shall be provided.

6. The Contractor shall provide insulated supports for power cables, designed to withstand maximum short circuit stresses specified for switchgear assembly.

7. Each incoming line and auxiliary feeder circuit breaker unit, as indicated on the Contract Plans, shall be furnished with two removable neon glow tubes per phase for "feeder alive" indication. The indicators shall be mounted for observation through windows of non-shatterable material located at a convenient viewing height. The neon tubes shall not be connected to switchgear buses, but be arranged for capacitive. Additional capacitive pickup devices shall be provided, if necessary to obtain adequate brilliancy for observing the indicators in well-lit substation. The installation of the neon tubes shall not reduce the impulse withstand level of the equipment.

I. Wiring and Terminal Blocks

1. Secondary and control wiring and terminal blocks shall be provided in accordance with Article 1.09, Section 16203 and as follows:

   a. Wiring and terminal blocks in switchgear housings and on circuit breaker removable elements and on the ground and test device shall be rated for 600 volts.
   b. Circuits requiring external connections shall be wired to outgoing wiring terminal blocks readily accessible from the front, with circuit breaker removable element in test or connected position.

J. Control Source

1. An ungrounded, two wire, 125 volt DC control bus shall be provided integral with the switchgear assembly. The control bus shall be No. 4 AWG, stranded switchboard wire insulated for 600 volts, minimum. The supply shall be wired to suitable screw type terminal blocks located at or near the middle of the switchgear lineup for top

connection to the supply conductors.

2. Each breaker control circuit shall be supplied from this bus through a separate set of disconnect switches and main (tripping circuit) fuses. Each circuit breaker closing circuit shall be provided with a secondary set of fuses with pullout disconnects to prevent blowing of main fuses on closing circuit faults.

3. Disconnect switches, fuse holders, and fuses shall be rated at 250 volts. Fuses shall be of the dual-element, cartridge type of appropriate rating. Necessary fuses shall be furnished with the equipment. In addition, a minimum of 10%, but not less than two spare fuses of each rating, shall be furnished.

K. Special Requirements

1. Each separate compartment within a switchgear cubicle shall be provided with an electric strip heater of adequate size to prevent condensation within the compartment. Heaters installed in a unit shall be monitored by means of an ammeter, scaled and marked for the heater load. Each cubicle shall be provided with an indicating light with blue lens to indicate operation of the heater and an ON-OFF switch. Heaters shall be provided with guards to protect operating personnel against accidental contact with hot surfaces.

2. An incandescent lamp receptacle, with conveniently located and properly labeled toggle switch or door operated switch, shall be provided in each compartment, accessible from the breaker draw out side of the switchgear. The Contractor shall also provide a duplex, grounding type receptacle in each switchgear unit, connected for 120-volt AC service.

3. Contractor shall provide a three-phase, four wire, 208/120-volt AC supply bus, No. 8 AWG minimum, throughout the switchgear assembly. The heater, light, and receptacle circuits shall be supplied from this bus through fusible pullout disconnects with dual-element cartridge type fuses located in each switchgear unit. Fuse holders and fuses shall be rated at 250 volts AC. Fuses shall be furnished with the equipment. A minimum of 10%, but not less than two spare fuses, of each rating shall be furnished. As far as practicable, loads shall be balanced between the phases of the supply bus. The supply shall be wired to terminal blocks located at or near the middle of the switchgear lineup for top connection to the incoming supply from the 208/120 volt distribution panel.

L. Nameplates

1. In addition to nameplates specified in Article 1.08, Section 16203, provide a nameplate on the front of the switchgear assembly, engraved with “DANGER - 13,800 VOLTS”. The nameplate shall have white letters, 2 inches high minimum, on red background. Two

similar nameplates shall be mounted on the rear of the switchgear assembly. Contractor shall furnish and ship loose eight similar nameplates for installation on exterior face of entry and exit doors of the Substation.

2. The legends of equipment nameplates shall be submitted to the Engineer for approval.

3. Switchgear identification nameplate shall be engraved "15 kV AC SWITCHGEAR".

M. Supervisory Control Requirements

The 15 kV switchgear assembly shall be provided with supervisory control, and indication measuring and interface devices specified in Article 2.02.C, Paragraph 5, this Section.

N. Circuit Breaker Test Cabinet

1. Contractor shall provide a wall mounted test cabinet for electrical operation of circuit breakers at location remote from the switchgear. The test cabinet shall include a control switch, similar to that furnished with the switchgear, to close and trip the breaker, red and green breaker position indicating lights, ten feet of control cable with a connector at the end for connection to the breaker, a set of properly sized fuses to protect the control circuit and screw type terminals for No. 8 AWG conductors of 125 volt DC control supply. An additional indicating light with white lens shall be provided for monitoring the control supply.

2. The control switch and the indicating lights shall be mounted on the door of the test cabinet. The wiring and terminal blocks shall be provided in accordance with Article 1.09, and the nameplates in accordance with Article 1.08, Section 16203.

3. A proper connector shall be provided for protecting the control cable at the point of entry. Provisions shall be made for storing or racking the control cable and the connector at the test cabinet.

4. The test cabinet shall be finished inside and out in accordance with Article 1.16, Section 16203.

O. Accessories

1. Contractor shall furnish special tools and equipment handling devices as recommended by the manufacturer for installation, assembly, adjustment and maintenance of the 15 KV switchgear and circuit breakers furnished**.** Special tools are defined as tools not readily available on the open market. All items shall be furnished as part of the initial delivery of the switchgear equipment.

2. Contractor shall also furnish and ship with the switchgear auxiliary

equipment and accessories necessary for operation, maintenance, testing and handling of removable components outside the switchgear assembly. These shall include, but not be limited to, the following:

1 - Floor-mounting steel cabinet with hinged doors with three point latching mechanism and key-locking handle and shelves for storing tools and accessories. Cabinet shall be fully rustproofed and finished in light gray enamel.
1 - Ground and test devices, rated 750 MVA, as specified in Article 2.04.F, this Section.
1 - Circuit breaker test cabinet, as specified in Article 2.03.N, this Section.
1 - "Fifth-wheel" device for handling breaker outside its housing.
1 - Racking-in crank.
1 - Manual spring charging handle.
1 - Set of tools required for breaker maintenance.
1 - Set of test plugs for drawout relays.
6 - 13.8 kV spare current limiting fuses for voltage transformers.
2 - One-quart cans of matching touch-up paint.
1 - Set of switchgear base channels for mounting the stationary units. These channels shall be shipped in advance of the switchgear for installation in the floor slab.
1 - 15 kV circuit breaker guide floor plate for aligning the breaker for insertion into the cubicle. In addition to aligning the AC breaker for insertion, this plate shall maintain the cubicle door open at an angle of 95˚ minimum, while the circuit breaker is being inserted or withdrawn.

P. Detailed Equipment Requirements

Contractor shall furnish and deliver to the Substation, the 15 kV switchgear assembly consisting of switchgear units of the type and quantity specified below. The individual units in the assembly shall be arranged to form a lineup shown on Contract Plans.

Individual switchgear units shall consist of the equipment, devices and appurtenances of the types and quantities detailed below.

1. Incoming Feeder Breaker, Device 52F

4 - Incoming feeder circuit breaker units, each including, but not be limited to the following:
1 - Metal-clad stationary unit, rated 750 MVA with 1200 ampere insulated bus and 1200 ampere tap
1 - 1200 ampere circuit breaker removable element, as specified, rated 750 MVA
3 - Current transformers, 600-5 ampere for relaying and indication, ANSI accuracy class C-100.
3 - Current transformers, 1200-5 ampere, for bus differential protection, ANSI accuracy class C-200.
3 - Directional overcurrent phase relays, induction type, very inverse time, 1.5-12 ampere with 20-160 ampere instantaneous unit, Device

67N.
1 - Residually connected directional overcurrent ground relay, induction type, very inverse time, 1.5-12 ampere with 2-16 ampere instantaneous unit, Device 67N.
1 - Overcurrent phase relay, induction type, inverse long time, 2.5-5 ampere, Device 51C, for cable overload alarm.
1 - Auxiliary relay for annunciation and supervisory indication of cable overload, with 125 volt DC coil and three single pole, double throw contacts, Device 51CX.
2 - Interposing relays to close and trip the circuit breaker via supervisory, with 125 volts DC coil, Devices 201C and 201T.
1 - Breaker auto-trip detection relay, high-speed type, for manual/auto trip alarm discrimination circuit, Device 74F.
1 - Auxiliary relay to operate in conjunction with Device 74F, with 125 volt DC coil, Device 74FX.
1 - Control switch TRIP-CLOSE with green, white, and red indicating lights, Device 1
1 - Indicating voltmeter, transformer rated, 0-18 kV scale.
1 - Voltmeter switch, 4-position OFF-AB-BC-CA.
1 - Indicating ammeter, transformer rated, 0-600 ampere scale.
1 - Current transducer, as specified, for telemetering, Device A-XD.
1 - Test switch, 10-pole, 4 potential, 6 current circuits
6 - Neon high voltage indicators installed or connected to line side of circuit breaker, two per phase
2 - Potential transformers, 14,400-120 volts, draw-out mounted with primary current limiting fuses, connected to line side of circuit breaker, open delta primary, grounded open delta secondary. May be mounted in a superstructure compartment.
1 - Pothead for three conductor, 600 kcmil copper, 15 kV, paper-insulated, lead-covered, shielded, PVC jacketed cable, entering from bottom.
1 - Set of space heaters with indicating light, ON-OFF switch and ammeter
1 - Set of DC and AC control and auxiliary power disconnect devices with fuses.

2. Unit Substation Feeder Breaker Type 1 - Devices 52FX

4 - Unit Substation feeder circuit breaker units Type 1, each including, but not be limited to, the following:
1 - Metal-clad stationary unit, rated 750 MVA with 1,200 ampere insulated bus and 1,200 ampere tap.
1 - 1,200 ampere circuit breaker removable element, as specified, rated 750 MVA.
3 - Current transformers, 100-5 ampere for relaying and indication, ANSI accuracy class C-10.
3 - Current transformers, 1,200-5 ampere for bus differential protection, ANSI accuracy class C-200.
3 - Overcurrent phase relays, induction type, very inverse time, 1.5-12 ampere with 10-80 ampere instantaneous unit, Device 50/51FX.
1 - Residually connected overcurrent ground relay, induction type,

very inverse time, 1.5-12 ampere with 2-16 ampere instantaneous unit, Device 50N/51N
2 - Interposing relays to close and trip the circuit breaker via supervisory, with 125 volt DC coil, Devices 201C and 201T.
1 - Breaker auto-trip detection relay, high-speed type, for manual/auto trip alarm discrimination circuit, Device 74F.
1 - Auxiliary relay to operate in conjunction with Device 74F, with 125 volt DC coil, Device 74FX.
1 - Control switch TRIP-CLOSE with green, white, and red indicating lights, Device 1.
1 - Indicating voltmeter, transformer rated, 0-18 kV scale.
1 - Voltmeter switch, 4-position OFF-AB-BC-CA.
1 - Indicating ammeter, transformer rated, 0-100 ampere scale, connected to phase B.
1 - Watt-hour demand meter, 120 volts, 2.5 ampere, three-phase, three wire, two elements, primary reading, for use with 20:1 ratio current transformers and 120:1 ratio potential transformers, with 15-minute interval indicating demand register and solid state pulse initiator with R/P ratio that will be determined by the supplier of the watt-hour meter.
1 - Current transducer, as specified, for telemetering, Device A-XD, connected to phase B.
1 - Key interlock system as specified in Article 1.14, Section 16203.
1 - Test switch, 10 pole, 4 potential, 6 current circuits
6 - Neon high voltage indicators installed on connected to line side of circuit breaker, two per phase.
2 - Potential transformers, 14,400-120 volts, draw-out mounted with primary current limiting fuses, connected to line side of circuit breaker, open delta primary, grounded open delta secondary. May be mounted in a superstructure compartment.
1 - Pothead for three conductor, No. 4/0 AWG copper, 15 kV, paper insulated, lead covered, shielded, cross-linked polyolefin jacketed cable, entering from bottom.
1 - Set of space heaters with indicating light, ON-OFF switch and ammeter.
1 - Set of DC and AC control and auxiliary power disconnect devices with fuses.

3. Unit Substation Feeder Breaker Type 2 - Device 52FX.

2 - Unit substation feeder circuit breaker units, Type 2, each including, but not be limited to, the following:
Same as Item 2 above, except the set of three terminal 100-ampere current transformers 0-100 ampere ammeter and the pothead for No. 4/0 AWG cables shall be deleted, the watt-hour demand meter current transformer ratio changed to 40:1 and the following added:
3 - Current transformers, 200-5 ampere, for relaying and indication, ANSI accuracy Class C-20.
2 - Sets of three cable terminal lugs for single conductor No. 4/0 AWG copper 15 kV solid insulated cable entering from top and bottom as shown on Contract Plans.

1 - Indicating ammeter, transformer rated, 0-200 ampere scale, connected to Phase B.

4. Unit Substation Feeder Breaker Type 3 - Device 52FX

2 - Unit substation feeder circuit breaker units, Type 3, each including, but not be limited to, the following:
Same as Item 2 above, except three 100-5 ampere current transformers, 0-100 ampere ammeter shall be deleted, the watt-hour meter current demand meter current transformer ratio changed to 40:1 and the following added:
3 - Current transformers, 200-5 ampere, for relaying and indication, ANSI accuracy Class C-20.
1 - Indicating ammeter, transformer rated, 0-200 ampere scale, connected to Phase B.

5. Bus Tie Breaker Unit - Device 52B

1 - Bus tie circuit breaker unit, including, but not be limited to, the following:
1 - Metal-clad stationary unit, rated 750 MVA with 1,200 ampere insulated bus and 1,200 ampere taps.
1 - 1,200 ampere circuit breaker removable element, as specified, rated 750 MVA.
6 - Current transformers, 1,200-5 ampere for bus differential protection, ANSI accuracy class C-200
6 - High-speed bus differential relays, Device 87B
2 - Bus differential lockout relays, manually reset type, rated for operation on 125 volts DC, Device 86B.
2 - Bus differential relay DC supply undervoltage relays, Devices 27B1, 27B2
2 - Phase sequence and undervoltage relays, three-phase, 120 volts, 60 Hz, connected to bus potential transformer secondaries, Devices, 47A, 47B.
2 - Indicating voltmeters, transformer rated, 0-18 kV scale.
2 - Auxiliary relays to operate in conjunction with Devices 47A and 47B, with 125 volt DC coil and three single pole, double throw contacts, Devices 47AX, 47BX.
2 - Indicating voltmeters, transformer rated, 0-18 kV scale.
2 - Voltmeter switches, 4-position OFF-AB-BC-CA.
2 - Voltage transducers, as specified, for telemetering, 15 kV bus potential, Device V-XD.
2 - Interposing relays to close and trip the circuit breaker via supervisory, with 125 DC coil, Devices 201C and 201T.
1 - Breaker auto-trip detection relay, high speed type, for manual/auto trip alarm discrimination circuit, Device 74B.
1 - Auxiliary relay to operate in conjunction with Device 74B, with 125 volt DC coil, Device 74BX.
1 - Control switch TRIP-CLOSE with green, white, and red indicating lights, Device 1.
1 - Set of space heaters with indicating light, ON-OFF switch and ammeter.

1 - Set of DC and AC control and auxiliary power disconnect devices with fuses.

6. Rectifier Transformer Feeder Breaker Unit - Device 52T

2 - Rectifier transformer feeder circuit breaker units, each including, but not be limited to, the following:
1 - Metal-clad stationary unit, rated 750 MVA with 1,200 ampere insulated bus and 1,200 ampere tap.
1 - 1,200 ampere circuit breaker removable element, as specified, rated 750 MVA.
3 - Current transformers, 300-5 ampere for relaying and indication, ANSI accuracy class C-50.
3 - Current transformers, 1,200-5 ampere for bus differential protection, ANSI accuracy class C-200.
3 - Overcurrent phase relays, induction type, extremely inverse time, 1.5-12 ampere with 10-80 ampere instantaneous unit, Device 50/51T.
1 - Residually connected overcurrent ground relay, induction type, very inverse time, 1.5-12 ampere with 2-16 ampere instantaneous unit, Device 50N/51N.
1 - Overcurrent phase relay, induction type, inverse long time, 4-8 ampere, for rectifier overload, Device 51R.
2 - Interposing relays to close and trip the circuit breaker via supervisory, with 125 volt DC coil, Devices 201C and 201T.
1 - Breaker auto-trip detection relay, high-speed type, for manual/auto trip alarm discrimination circuit, Device 74F.
1 - Auxiliary relay, to operate in conjunction with Device 74F, with 125 volt DC coil, Device 74FX.
1 - Control switch TRIP-CLOSE with green, white, and red indicating lights, Device 1.
1 - Indicating ammeter, transformer rated, 0-300 ampere scale, connected to phase B.
1 - Watt-hour demand meter, 120 volts, 2.5 ampere, 60 Hz, three phase, three wire, two element, primary reading, for use with 60:1 ratio current transformers and 120:1 ratio potential transformers, with 15-minute interval indicating demand register and solid state pulse initiator with R/P ratio that will be determined by the supplier of the watt-hour meter.
3 - Potential transformers, 14,400-120 volts, draw-out mounted, with primary current limiting fuses, connected to the main bus, grounded wye primary, grounded wye secondary.
3 - Auxiliary potential transformers, 69.4-120 volts, grounded wye primary, broken delta secondary, for Device 67N polarization
1 - Test switch, 10 pole, 4 potential, 6 current circuits.
1 - Set of cable terminal lugs for three single-conductor, No. 4/0 AWG copper, 15 kV, solid-insulated, shielded cable.
1 - Set of space heaters with indicating light, ON-OFF switch and ammeter.
1 - Set of DC and AC control and auxiliary power disconnect devices with fuses.

0.4 RECTIFIER TRANSFORMERS

A. General

1. Rectifier transformers shall be indoor, metal enclosed, open ventilated, natural convection cooled (Class AA), dry type with cast coils, using building air for cooling under ambient conditions as specified in Article 2.01, this Section.

2. The transformers shall be designed to meet the requirements of NEMA RI9 for extra heavy duty traction service. Transformers shall fully coordinate with and operate in conjunction with associated rectifiers specified under Article 2.05, this Section.

3. Contractor shall submit, 30 days prior to the Design Conference, for Engineer's approval, design calculations for the transformer rated for use with 3,000 kW rectifier, which shall include, but not be limited to, the following:

   - Resistance
   - Impedance
   - X/R Ratio
   - Temperature Rise Curve
   - Power Loss Curve
   - Efficiency - Load Curve
   - Power Factor - Load Curve

4. Two transformers shall be furnished and shipped to the Substation.

B. Ratings

1. The kVA rating of each transformer shall commensurate with its associated rectifier as detailed in Article 2.05, this Section.

2. Average winding temperature rise by resistance for the two hour overload cycle as specified shall not exceed 65˚C with an average ambient temperature of 30˚C and a maximum ambient temperature of 40˚C during a 24 hour period. Winding insulation shall be Class F rated for a total temperature of 155˚C or better.

3. High voltage windings shall be copper, three phase 60 Hz, 13.8 kV nominal, delta connected, suitable for use on an effectively grounded system. High voltage winding insulation class shall be 15 kV, rated for a basic impulse level (BIL) of 110 kV, minimum.

4. Transformer shall have two three phase low voltage copper windings: one delta connected, the second wye connected, arranged in accordance with ANSI Circuit No. 31, as defined in ANSI Standard C34.2, to provide twelve-phase, multiple delta-wye, double-way supply to the rectifier. Voltage and related characteristics shall commensurate with rectifiers specified under Article 2.05, this Section. Low voltage winding insulation class shall be 1.2 kV, rated

for a BIL OF 45 kV, minimum.

5. Transformer winding current rating at any tap position shall be based on rectifier rated current for initial (590 volt) operation.

C. Impedance

1. Impedance of transformer shall be as low as possible, consistent with good design and shall be determined by the overall requirements of the transformer, rectifier, AC and DC buses, particularly with respect to the DC output voltage regulation specified in Article 2.05, this Section, and the limitation of fault current magnitudes in accordance with rectifier diode capabilities and the interrupting ratings of DC circuit breakers. The specified maximum and minimum short circuit capacity of the incoming 13.8 kV service at the Substation shall be used for determining the total voltage regulation and the short circuit capacity of the power rectifier equipment.

D. Taps

1. Nine 2-1/2% no load full capacity taps shall be provided in the high voltage windings, as tabulated below, for adjustment of sustained departures in AC supply voltage and for adjustment of output voltage as required for initial and future operation of the rectifiers.

	H.V. Winding Tap Position	For Rectifier Voltage Rating	Full Load Ouput
1	14,490 V AC	590 V DC	
2	14,145 V AC	590 V DC	
3	13,800 V AC	590 V DC	
4	13,455 V AC	590 V DC	
5	13,110 V AC	590 V DC	
6	12,765 V AC	590 V DC	
7	12,420 V AC	590 V DC	
8	12,075 V AC	590 V DC	
9	11,730 V AC	590 V DC	

2. In addition, application of 13,800V AC to the transformer with its tap changer at position seven shall result in future rectifier output of 650 volts DC at rated full load. For future operation, the taps above and below tap seven shall be suitable for adjustments, in 2-1/2% increments, for the deviations in the nominal 13,800 volt supply system voltage.

E. Power Circuit Terminations

1. Transformer high voltage terminals shall be provided with bolted type terminal lugs with two-bolt tongue, in accordance with Article 1.07, Section 16203, for terminating one No. 4/0 AWG stranded copper cable per phase. Terminals shall be located to provide ample space

for stress-coning the three 15 kV, single conductor, ethylene-propylene insulated, shielded cable, entering from below.

2. Low voltage terminals shall be located in the transformer enclosure, in an air-filled terminal chamber or in a flanged throat, arranged for direct, bolted connection to the anode bus duct specified in Article 2.07, this Section, entering from below and as approved by the Engineer. Bolted, readily removable links shall be provided, in accordance with Article 1.06, Section 16203, for connecting the bus conductors to the transformer terminals. The terminal enclosure and bus enclosure shall be joined by an approved bolted connection, providing ready means of separating the bus duct from transformer. Openings with bolted-on covers shall be provided for access to the connecting links.

F. Wiring and Terminal Blocks

1. All devices furnished with the transformer shall be factory wired as far as practicable. Circuits requiring external connections shall be wired to the terminal in the instrument compartment for connection of the field wiring entering from the top.

2. Wiring for control and auxiliary circuits and terminal blocks shall be rated for 600 volts, provided in accordance with Article 1.09, Section 16203. Minimum wire size shall be No. 12 AWG, except low voltage, low energy connections between components and alarm device pigtails may be No. 16 AWG.

3. Where wiring and/or cable needs to be supported within the transformer at a metallic component, care shall be taken to provide a suitable dielectric insulator between the wire and/or cable and the metallic component providing the support so that the wire/cable is not in direct contact with the metallic support.

G. Audible Sound Level

1. Audible sound level shall not exceed 60 decibels (A) at no load with excitation on the transformer, when measured in accordance with conditions outlined in ANSI Standard C57.12.91 and in accordance with OSHA Volume 37 No 202 Point II, Section 1910.95.

2. Major sound-producing components and the transformer enclosure shall be acoustically treated, if required, to meet this criterion.

H. Construction

1. Transformer shall be provided with rigid, self-supported, electrically welded steel structure, enclosed with not less than 12 gauge formed steel sheets. The enclosure shall be constructed of structural members of sufficient strength to provide trouble-free operation of doors and to prevent damage and distortion in shipping, handling and

during installation.

2. Full height hinged doors shall be provided in front of the transformer, for access to the transformer, incoming primary connections, the tap changer terminals and control circuit terminals. Doors shall be formed of sheet steel and shall be properly reinforced against distortions by suitable flanges and stiffening members. Hinges shall be heavy duty, of a type approved by the Engineer. Doors shall be securely fastened in closed position with a minimum of three wrench operated latches. Stops shall be provided to hold doors securely in the open position.

3. Similar full-height, hinged doors shall be provided in the rear for access to the transformer and incoming primary connections.

4. Bolted-on covers shall be provided for access to transformer secondary terminals, for connection to anode buses.

5. Removable, transparent insulating barriers shall be mounted inside the enclosure across the front and rear doorways to block access to the tap charger terminals, the coil assembly and buses and cable, unless the barriers are removed. The barriers shall be firmly bolted to transformer structure.

6. Openings shall be provided in doors, bolted-on covers and fixed panels for circulation of air through the transformer. Openings shall be screened for personnel safety. Screens shall be of expanded metal of gauge approved by the Engineer, with openings approximately 1/4 inch by 1 inch. Cooling air shall enter the transformer enclosure above the floor level.

7. Transformer shall be designed to limit the temperature rise of readily accessible external parts and the enclosure to 65˚C over an ambient temperature of 40˚C during the specified duty cycle.

8. An insulated compartment, formed by sheet steel barriers, shall be provided for housing the instruments, relays and outgoing wiring terminal blocks. The compartment shall be located in the front of the unit and shall have a full-access hinged door. Door shall be securely fastened in the closed position with two latches, easily opened without the use of tools. Indicating instruments shall be mounted through the door of the compartment.

9. Laminations shall be of non-aging alloy. Joints in windings and tap charger terminals shall be brazed. Core bolt insulation shall be high temperature resistant type. Entire coil and core assembly shall be braced and bolted adequately to reduce the sound level and to prevent displacement and/or distortion under all normal conditions of handling and during operation under short-circuit conditions, based on the 13.8 kV system fault supply of 750 MVA at transformer high voltage terminals and the X/R ratio of four. Locking provisions shall

be made for all inside bolted members and connections. Serial number shall be stamped on core or core clamp in conspicuous place.

10. Windings shall be of the totally encapsulated, moisture resistant cast coil design. The insulating epoxy resin material shall be flame-retardant and track-resistant, capable of meeting the requirements of UL94 for flame retardant properties. The chemical, electrical and mechanical properties of the insulating materials used in insulation and encapsulation of windings shall be submitted for Engineer's approval at the Design Conference.

11. Core and coil assembly shall be mounted on base constructed of I-beams or channels. Base shall be designed to distribute the weight of the transformer evenly to the enclosed base area of the transformer. This requires structural members around the periphery of the base and intermediate cross members spaced not more than 12 inches on centers or more widely spaced cross members with a bottom plate of sufficient strength. Base shall be suitable for skidding in any direction on rails or rollers. Lifting lugs shall be provided for lifting the core and coil assembly. Provisions shall be made for anchoring the transformer to substation floor.

12. Tap changer terminal shall be located for easy access from the front after opening the doors and after removal of the insulated barriers.

I. Protective Devices and Accessories

1. Each rectifier transformer shall be provided with protective devices and accessories, including, but not be limited to, the following:

   1 - Temperature indicator assembly, consisting of three thermocouple or thermistors (one in each phase winding) and solid state circuitry for monitoring winding hottest spot temperature and providing output with two-step temperature settings and electrically independent contacts which close with rising temperature: for alarm (first step, Device 49T), and tripping (second step, Device 49TH). Means shall be provided for manual check of the temperature of each phase coil assembly. Indicator shall be either analog or digital (1/2 inch high numbers, minimum), in degrees C. System shall operate on 120 volt, 60 Hz supply, derived from the 120 volt reliable supply at the DC switchgear. Output contacts shall be rated for operation on 125 volt DC.
   1 - Temperature indicator, to show the air temperature within the transformer enclosure.
   2 - Grounding pads on diametrically opposite corners of base, each provided with a bolted type terminal lug with two-bolt tongue, in accordance with Article 1.07, Section 16203, for stranded copper ground cable with the range of No. 4/0 AWG through 500 kcmil.
   1 - Stainless steel nameplate showing winding connections, taps, voltages, ratings, commutating impedance, serial number, weight, and other information as required by Standards in accordance with

ANSI C57.12.00 and as directed by the Engineer. Voltage and current data shall be given for both, the initial and future operation.

J. Nameplates

1. In addition to nameplates specified in Article 1.08, Section 16205, provide a nameplate on front and rear of the transformer enclosure, engraved "DANGER -13,800 VOLTS". The nameplate shall have white letters, two inches high, minimum, on red background.

2. Inscription of nameplate shall be submitted to the Engineer for approval.

3. Equipment identification nameplates shall be engraved "RECTIFIER NO. 1 TRANSFORMER" and "RECTIFIER NO. 2 TRANSFORMER".

K. Finish

1. Prepare all surfaces of the transformer and the base in accordance with Article 1.16, Section 16203, and finish with two coats of semi-gloss ANSI-61 light gray paint.

2. One quart of matching touch-up paint shall be stripped with each transformer.

0.5 RECTIFIERS AND ACCESSORIES

A. General

1. Rectifiers shall be indoor, metal enclosed, natural convection cooled, using building air for cooling under ambient conditions as specified in Article 2.01, this Section, for 12 phase multiple double way rectification.

2. Two rectifiers shall be furnished and shipped to the Substation.

3. The rectifiers shall be supplied with AC power directly from the rectifier transformers specified in Article 2.04, this Section, to serve as the source of supply for the DC switchgear specified in Article 2.06, this Section. The rectifiers shall be operated with their structures high-resistance grounded. Rectifiers shall be designed to meet the requirements of NEMA RI9 for extra-heavy duty traction service.

4. Rectifiers shall be designed for parallel non-attended operation. Rectifiers shall function as integrated units with associated transformers and DC switchgear. Rectifiers and accessories shall also be capable of parallel operation with existing converting equipment supplied from Authority's 13.8 kV 60 Hz cable network. Data of existing equipment may be obtained from _____, Project Manager, Massachusetts Bay Transportation Authority, Design and Construction, 500 Arborway, Jamaica Plain, MA 02130

Telephone (617) 222-____.

5. Contractor shall submit 30 days prior to the Design Conference, for Engineer's approval, a set of complete design calculations for the 3000 kw rectifier, which shall include but not be limited to, the following.

   - Voltage Regulation Curve
   - No load voltage for initial and future operation
   - Power factor - Load Curve
   - Efficiency - Load Curve
   - Harmonic Amplitude - Load Curve for 11th, 13th, 23rd and 25th harmonics
   - Commutation Reactance for X/R - 4 and 7
   - Momentary Peak and Sustained Short Circuit Current (one rectifier in operation)
   - Momentary Peak and Sustained Short Circuit Current (two rectifiers in operation)
   - Commutation Factor
   - Calculations to show compliance with Specification on number of parallel diodes furnished

B. Structures

1. Rectifier units shall be metal enclosed, provided with self-supported, electrically welded steel structures. Each assembly shall consist of a silicon power rectifier section and a control/auxiliary section, arranged to form a continuous, freestanding unit. The enclosures shall be constructed of structural members of sufficient strength to support the bus ducts, which interconnect the rectifier-to-rectifier transformer, DC switchgear and the negative equalizer bus and drainage board.

2. Rectifier section shall be provided with hinged front and rear doors for easy access to diodes, fuses, surge protection devices, heat sinks and buses for inspection, maintenance and cleaning. Each door shall be provided with safety glass windows, arranged to permit inspection of all indicating fuses and fuse failure indicating lights of surge protection devices. All doors shall be securely fastened in the closed position and easily opened without the use of tools. Doors shall be provided with stops to hold them securely open at 90˚.

3. The control/auxiliary section shall be completely isolated from the rectifier section by suitable sheet steel barriers. It shall contain the instruments and devices required for control and monitoring of the rectifier transformer, rectifier and the rectifier DC main breaker. The control/auxiliary section shall be provided with hinged front and rear doors, for access to devices and terminal blocks and for mounting of relays, instruments and control devices. The doors shall be formed of sheet steel and shall be properly reinforced against distortions by suitable flanges or stiffening members. The door shall be securely

fastened in the closed position and easily opened without the use of tools.

4. All control and supervisory circuit devices located in the control/auxiliary section are operated on 125 volts DC or 120 volts AC. Where the use of higher voltage is unavoidable, such circuits shall be connected with red-colored wire.

5. All doors of the rectifier section and the doors of control/auxiliary section compartments containing exposed buses or devices operated on 650 volt DC positive potential shall be provided with interlocks designed to prevent energization of the rectifier while any of the doors are open, and to de-energize the rectifier when any of the doors are opened while the rectifier is in operation. Control devices and wiring operated on 650 volt DC shall be grouped in separate compartments as far as possible so that the devices operated at lower voltage are accessible for maintenance without the need of de-energizing the rectifier.

6. All components within the control/auxiliary section shall be located for easy access for maintenance and inspection. The arrangement of devices will be subject to the approval of the Engineer.

7. Openings in doors or fixed panels on the rectifier section which are utilized for circulation of air through the rectifier, shall be screened for personnel safety. Screens shall be expanded metal of gauge approved by the Engineer, with openings approximately 1/4 inch x 1 inch. Cooling air shall enter the rectifier enclosure above the floor level.

8. All surfaces of the enclosure shall be finished in accordance with Article 1.16, Section 16203. One quart of matching touch-up paint shall be shipped with each rectifier.

9. *The door for the low voltage control compartment shall be designed so that it can be opened without tripping the protective 33 Device (rectifier compartment door safety interlock).*

C. Buses and Power Connections

1. Rectifier internal buses shall be copper, provided in accordance with Article 1.06, Section 16203. Aluminum may be used for diode heat sinks, also for certain current carrying sub-assemblies approved by the Engineer. Appropriate barriers shall be provided to separate the positive and negative buses within the rectifier. Suitable means, approved by the Engineer, shall be employed to prevent corrosion at connections of dissimilar metals.

2. Permanent corrosion inhibiting coating shall be provided for all bolted connections to reduce maintenance.

3. Rectifier anode (AC) and positive and negative cathode (DC) terminals shall be copper, located at the top of the enclosure, in an air-filled terminal chamber or in a flanged throat, arranged for direct, bolted connection to the anode and cathode bus ducts specified in Article 2.05, this Section and as approved by the Engineer. Bolted, readily removable flexible links shall be provided, in accordance with Article 1.06, Section 16203, for connecting the bus conductors to rectifier terminals. The terminal enclosure and bus enclosure shall be joined by an approved bolted connection, providing ready means for separating the bus duct from the rectifier. Openings with bolted-on covers shall be provided for access to the connecting links.

D. Ratings

1. Each rectifier shall have a continuous full load output rating of 3,000 kW at a maximum ambient room temperature of 40˚C during initial operation and 3,300 kW during future operation. Rated full load output voltage for determining the continuous current rating of the rectifier shall be taken as 590 volts DC. After constant temperature rise is reached following continuous full load, it shall be capable of operating at guaranteed overload equal to 150% of full load current for two hours and superimposed cyclic overload consisting of five periods of 300% full load current for one minute, equally spaced throughout the two hour period, followed by one period of 450% full load current for fifteen seconds at the end of the two hour period. The rectifiers shall be designed for two two-hour overload duty cycles within a 24 hour period, spaced six hours apart.

2. The rectifier shall be capable of carrying the specified overload with one diode removed from service in each phase leg of the rectifier without exceeding the safe junction temperature of the remaining diodes.

3. Loss of one diode in each phase leg shall not adversely affect the ability of the rectifier to withstand short circuit.

4. Each rectifier shall be capable of withstanding a bolted short circuit on the rectifier output terminals immediately following (within one second or less) the two hour overload period specified above until fault is cleared by rectifier AC circuit breaker, without damage to any component, including protective fuses and rectifier elements.

5. Each rectifier shall have a full overall efficiency of not less than 94%, a displacement power factor above 95%, lagging. The voltage regulation characteristic, based on the minimum short circuit supply MVA and the X/R ratio of the incoming 13.8 kV services specified in Article 2.02.B, this Section, shall be such as to provide output voltage within the limits set forth below when the AC system voltage at no load corresponds to transformer tap voltage.

   These limits shall be met on all transformer taps. All DC values shall

be based on use of averaging type meters.

Output Voltage-Direct Current

Output Current	Initial Operation	Future Operation
0.5% Full load	636 to 626	700 to 689
100% Full load	600 to 590	661 to 650
150% Full load	582 to 572	641 to 630
300% Full load	528 to 507	582 to 558
450% Full load	474 to 425	522 to 468

6. The rectifier transformers, AC and DC buses and the DC switchgear assemblies specified herein shall be capable for continuous operation on the voltages specified above.

E. Number of Diodes Required

1. The manufacturer shall provide a sufficient number of diodes per phase leg to fulfill all the requirements of this Specification but in no case shall the number of diodes provided per phase leg be less than the letter "D" determined by the following calculations:

Let D = Minimum quantity of diodes per phase leg.

Let C = Published diode peak surge current rating in amperes (maximum peak value of rated non-recurrent one cycle sinusoidal current on a 60 Hz basis). Must conform with NEMA-EIA Standards for Silicon Rectifier Diodes and Stacks, NEMA Publication No. SK60 (EIA RS-282) Reaffirmed by NEMA 1972, Section 4.01, Para. 3.

Let Xa/Ra = Overall reactance-to-resistance ratio, including alternating current supply system, transformer, bus duct, and rectifier.

Let K = Transient RMS factor, for applicable X/R ratio, from AIEE conference paper of May 17, 1961 entitled "Short Circuit Currents In Power Rectifier Systems" by Johannes Schaefer, Sipplingen/Bodensee, Germany. See Table 1 at the end of Part 4 of this Section.

Let Es = Rectifier transformer low voltage winding voltage, line-to-line, at no load.

Let Iss = Average DC sustained short circuit current with rectifier output terminals bolted, with 550 MVA supply system at 13.8 kV, X/R=4 and

$$Z = \sqrt{\left(R_a^2 + X_a^2\right)} \quad and \quad Iss = \frac{1.35\ Es}{\sqrt{3}\ Z}$$

$$\text{Then } D = \frac{1}{2}\left[\frac{0.74\ Iss + \left(\frac{C}{\sqrt{2}}\right)\left(\frac{1}{K}\right)}{\left(\frac{C}{\sqrt{2}}\right)\left(\frac{1}{K}\right) - 0.0074\ Iss}\right] + 1$$

F. Rectifier Protection

1. Rectifiers shall be designed so that the diodes and other rectifier elements are protected against overcurrent and fault currents by phase and ground instantaneous and time overcurrent relays, Devices 50/51, 50N/51N, 51R. The overcurrent relays shall be selective with the individual diode fuses so that the fuses will not blow on a through fault. Diode fuses shall blow on a diode shorting failure only.

2. Rectifier heat sinks shall be provided with thermal devices, Device 26RH, which shall take the rectifier out of services and prevent rectifier operation under any conditions where the rectifier elements and fuses are no longer afforded complete protection by the overcurrent relays. These thermal devices shall be mounted and wired to permit easy removal.

3. Each rectifier unit shall be adequately protected against transient surge voltages caused by lightning, faults or switching operations and the DC spikes caused by operation of trains. Contractor shall submit the surge protection method and devices he plans to use to the Engineer for approval.

G. Wiring and Terminal Blocks

1. Wiring for control and auxiliary circuits and terminal blocks shall be rated for 1000 volts DC service, minimum, provided in Accordance with Article 1.09, Section 16203.

2. Minimum size of wiring shall be No 12 AWG, except internal wiring of devices and device pigtails may be No. 16 AWG.

3. Circuits requiring external connections shall be wired to outgoing wiring terminal blocks in the control/auxiliary section for connection of field wiring entering from the top.

4. All elements of control devices operated on 650 volts DC shall be connected with red-colored wire.

H. Control Sources

1. Rectifier control and alarm circuits will receive the 125-volt DC supply from the station battery. Rectifier lockout relay and annunciator circuits shall be connected to this supply through a separate set of disconnect switches and properly sized fuses, rated for 1000 volt DC service, minimum. Contractor shall furnish an undervoltage relay, Device 27RA, for the circuits, for local alarm.

2. The 120-volt, 60 Hz supply for rectifier heat sink over temperature

device circuit will be derived from the 120 volt reliable supply at the DC switchgear. Contractor shall furnish an undervoltage relay, Device 27RB, for the circuit with time-delayed contacts, for local alarm.

3. Terminal blocks, rated for 1000 volts DC services, minimum, shall be provided in the control/auxiliary section in accordance with Article 1.09, Section 16203, for supply conductors entering from top.

I. Special Requirements

1. The control/auxiliary compartment of the rectifier shall be provided with electric space heaters to prevent condensation within the compartment during shutdown periods. An ammeter shall be provided to monitor the space heater circuit. The ammeter shall be properly scaled and marked for the heater load. In addition, an indicating light with blue lens shall be provided to indicate operation of the heaters and an ON-OFF switch.

2. Fluorescent lighting fixtures with conveniently located and properly labeled external toggle switch shall be provided in the rectifier section and in each compartment which contains relays, control devices and outgoing wiring terminal blocks. The lighting fixtures in the rectifier section shall be located so that adequate lighting is provided for normal maintenance and observation, and to permit inspection of all indicating fuses and other devices within the unit.

3. The heater and lighting circuits shall be rated for operation on a single phase, three wire, 208/120 volt circuit. All devices shall be completely wired by the Contractor and the circuit extended to a suitable terminal block for top connection to supply conductors. The lighting fixtures, light switches, space heater devices and terminal blocks shall be insulated from rectifier enclosure for a minimum of 1000 volts DC.

4. A non-reset type elapsed time meter shall be provided in front of the control/auxiliary section, wired through series-connected "a" contacts of the rectifier AC circuit breaker, Device 52T and rectifier DC circuit breaker, Device 72R, to record the in-service time of the rectifier unit. The instrument shall be wired to outgoing wiring terminal block for top connection to supply conductors. The elapsed time meter shall be rated 120 volts, 60 Hz and shall have six-digit display to record hours and tenths of hours. Instrument shall be connected to 120 volt, 60 Hz reliable supply.

J. Audible Sound Level

1. The maximum average audible sound level produced by the entire rectifier unit under no-load condition shall not exceed 55 decibels (A). Major sound-producing components, their supports and rectifier enclosure shall be acoustically treated, if required, to meet this

criterion.

2. One rectifier unit shall be tested in accordance with the requirements of the old NEMA Standard TR1 or the latest applicable NEMA standard considering the rectifier as the sound source.

K. Nameplates

1. In addition to nameplates specified in Article 1.08, Section 16203, the Contractor shall provide nameplates, mounted in the front and rear of each rectifier assembly, engraved "650 VOLTS DC PRESENT IN RECTIFIER COMPARTMENT". The nameplate shall have white letters, two inches high, minimum, on red background. Similar nameplates, engraved with one-inch high letters "650 VOLTS DC PRESENT IN THIS COMPARTMENT" shall be provided on the door of each compartment, which contains control devices operated on 650 volt DC.

2. The legend of nameplates shall be submitted to the Engineer for approval.

3. Equipment identification nameplates shall be engraved "RECTIFIER NO. 1 - 3000 kW" and "RECTIFIER NO. 2 - 3000 kW".

L. Supervisory Indication

1. Two normally open contacts each of the following devices, wired to outgoing wiring terminal blocks, shall be provided within each rectifier for remote indication via Authority's supervisory systems:

   Device 86 (rectifier lockout)
   Device 30 (substation trouble)

M. Detailed Equipment Requirements

1. Each 3,000 kW indoor metal enclosed 12-pulse double way silicon rectifier assembly shall include, but not be limited to, the following:

   1 - Lot of air-filled terminal chambers or flanged throats, connectors and hardware for direct bolted connections to AC anode bus and DC positive and negative cathode buses entering from above.
   1 - Silicon diode and heat sink assembly: Diode shall be connected one in series per leg and shall have a minimum repetitive peak reverse voltage rating of 2,200 volts. Each individual silicon diode shall be hermetically sealed and mounted on air-cooled heat sink adequate for maximum heat dissipation. A current balancing arrangement employing reactors, or other equivalent means, shall be provided to ensure constant current balance between paralleled diodes of each individual phase and to maintain each individual diode current within guaranteed capability under all load conditions up to and including the current peaks specified in Article 2.05.D, this Section, with one fuse per phase leg open. With any diode fuse open

at any and all rated loads, the current in any other parallel diode in the same phase leg shall not exceed its pro rate share by an amount greater than one percent times the number of paralleled diodes in that phase leg, or by an amount not greater than 20%, whichever is greater. Pro rate share is defined as the total rated phase leg current divided by the number of paralleled diodes in that phase leg. The current balancing method is subject to approval by the Engineer. Reliance upon matched diodes for current balancing purpose will not be acceptable, unless the Contractor can prove to the satisfaction of the Engineer that each diode selected at random from a production run of diodes of the type to be installed in the rectifier has a tolerance sufficiently close to ensure the specified current balance between the paralleled diodes.

1 - Set of current limiting fuses: One fuse shall be connected in series with each diode, complete with fuse monitoring system. Fuse monitoring system shall consist of a mechanical target which is clearly visible when illuminated by the lights provided with the rectifier unit.

1 - Set of heat sink over-temperature devices. A total of 24, circuit opening on rising temperature, bi-metallic thermal devices shall be furnished and mounted on diode heat sinks. Twelve devices, six on positive and six on negative heat sinks, shall be connected to provide first-step high temperature alarm, Device 26R. Twelve devices, six on positive and six on negative heat sinks shall be 64 connected to provide second-step high temperature trip and lockout, Device 26RH. The devices shall be selected to allow for overloads specified in Article 2.05.D, this Section. Circuit shall be self-monitoring with provisions to actuate the alarm or trip circuits, after a time delay of approximately one second, in the event of detection of high temperature, device or circuit failure or loss of AC auxiliary power to Devices 26RX and 26RHX. Provide a white light for Device 26RHX, 120 volt, AC control source and mount on the rectifier door with suitable identifying nameplate. Suitable isolating transformers shall be provided to isolate thermal switches from control circuits and from other thermal switches on heat sinks not rigidly at the same potential.

1 - Resettable counter mounted in front of the control/auxiliary section, to count the number of trips due to heat sink overtemperature.

1 - Set of surge protective devices. The surge protective devices shall limit the repetitive reverse voltage surges, induced during lightning, faults and switching or by operation of trains, across the diode to within 75% of the peak reverse voltage (PRV) rating of the diodes. The transient surge voltage is assumed to have a crest of 3,000 volts and 1.5 x 40 microsecond wave shape of either polarity, applied to all rectifier terminals, while operating at rated current and full rated temperature. In addition, the rectifier shall withstand lightning surges of 75 kV crest and 1.5 x 40 microsecond wave shape, applied to rectifier output terminals. Where surge protective devices are protected by a circuit interrupting component, a monitoring circuit employing a neon lamp shall be provided to indicate an inoperative circuit. The monitoring circuits shall be provided with a relay, Device

99Y, to actuate alarm in the event of fuse or surge protective device failure.
1 - Interphase transformer or a set of mutually coupled reactors, for interconnecting the negative side of the two three-phase double-way rectifier circuits. Interphase transformer shall have the voltage and current ratings and the ability to withstand short circuits equal to those specified in Article 2.05.D, this Section, for the rectifier and a designated amount of phase control to properly commutate the phase displacement of the paralleled rectifier units.
1 - Set of interlock switches designed to de-energize the rectifier when any one rectifier access door is opened exposing 650-volt "live" parts. The interlocks shall trip Device 86 and actuate alarm. Device 33.
1 - Temperature indicator to show the air temperature within the rectifier enclosure.
1 - Lot of electric strip heaters, lights and accessories.
1 - Control/auxiliary compartment, completely wired, with all relays, controls and auxiliary devices, including but not limited to:
1 - Master control relay, electrically reset type. Device 4.
1 - Annunciator, solid state type, with backlighted nameplates consisting of 30 alarm positions, arranged five high and six wide. Annunciator shall be rated for operation on 125 volt DC and shall be provided with three push buttons for acknowledge, reset and test functions. Annunciator cabinets shall be insulated from rectifier enclosure for a minimum of 1,000 volts DC. List of nameplate inscriptions shall be provided for review by the Engineer. All alarm points for which the actuating contacts are remote from rectifier unit and all retransmitting contacts shall be wired to outgoing wiring terminal blocks for connection to field wiring entering from top. Device 30.
1 - Rectifier and transformer auxiliary DC circuit undervoltage relay, Device 27RA.
1 - Rectifier and transformer auxiliary AC circuit undervoltage relay, Device 27RB.
1 - Set of 125 volt DC control power disconnect devices with overload protection, all rated at 1,000 volts DC and wired to terminal blocks for supply conductors entering from top.
1 - Set of ground detector circuit components, including relays, Devices 64R and 64RX, DC power supply and related devices, as detailed in Article 1.05.C, this Section.
1 - Lockout relay, manually reset type. Device 86.
1 - Lockout relay circuit undervoltage relay. Device 27R.
1 - Conditional lockout relay, electrically reset type. Device 86X.
1 - Set of auxiliary relays for heat sink overtemperature devices. Devices 26RX and 26RHX.
1 - One set of insulated anchor blocks for each rectifier assembly, as required. These shall be shipped in advance of equipment.

0.6 DC SWITCHGEAR ASSEMBLY

A. General

1. The switchgear assembly shall consist of indoor metal-enclosed; self-supporting structures rated for operation on 750 volt DC traction service.

2. The switchgear assembly will be directly supplied from the 3,000 kW power rectifiers specified in Article 2.05, this Section, and shall serve as the DC traction power supply to the traction feeders as outlined in this Specification. Switchgear shall be suitable for operation with its structure high-resistance grounded.

3. Provisions shall be included to accommodate future extension from both ends of the switchgear assembly.

B. Switchgear Assembly and Circuit Breaker Units

1. The metal-enclosed switchgear assembly shall consist of rigid self-supporting and self-contained electrically welded steel structures. The individual breaker units shall be enclosed with not less than 12 gauge formed steel sheets. The individual units shall be bolted to each other to form a continuous, free-standing switchgear assembly, divided into shipping sections as specified in Article 2.02.A, this Section.

2. Hinged doors shall be provided at front and rear of each circuit breaker unit, suitable for mounting relays, meters, instruments and control devices. Doors shall be formed of sheet steel and shall be properly reinforced against distortions by suitable flanges and stiffening members. Hinges shall be heavy duty of a type approved by the Engineer. Full height doors shall be securely fastened in the closed position with a minimum of three latches easily opened without the use of tools. For doors less than the full height of the equipment, a minimum of two latches will be acceptable. Doors shall be provided with automatic self-stopping capabilities, with the automatic stop at 45˚, the second at 90˚ and the third at 120˚. Manual defeating mechanism shall be provided for moving the door from one stop to another. At each stop, the door shall be held securely in the open position. With the front door of any compartment open at 90˚ position, it shall not prevent the adjacent compartment door from being opened and its breaker completely removed from its housing.

3. Separate, steel-enclosed compartments shall be provided for the circuit breaker, main bus, outgoing buses, feeder cables, and for relays, instruments and control devices. All compartments shall be sufficiently gas tight to assure that no ionized gas will pass from one compartment to the other.

4. Compartments for circuit breaker, outgoing cables, and for relays and control devices, shall be provided with a separate hinged door for servicing without exposing circuits in adjacent compartment. In lieu of the hinged doors, circuit breaker compartments may be provided

with hinged closure panels attached to breaker removable element. Cable compartments shall be accessible for connection of power cables from the rear of the unit.

5. The bus compartment containing the main (positive) bus and bus taps shall be isolated from all rear cubicle compartments by an insulated barrier arranged to provide full access to the bus and the taps. The barrier shall be separate from the switchgear compartment door and shall be attached to the switchgear frame by insulated threaded bolts. Hard-to-reach nuts on the other side of the bolts shall not be employed. The barrier shall be clearly labeled to indicate that the main bus is behind it.

6. Barriers shall be provided at the side of cubicles to insulate the bus compartment of adjacent units. A similar, completely isolated compartment shall be provided for termination of outgoing power cables. The cable compartment of each circuit breaker unit shall be isolated from the cable compartment of adjacent unit.

7. The breaker compartment shall be completely enclosed except for the insulated vent opening at the top, designed for rapid exhaust and deionization of ionized gases. The design shall prevent striking an arc to conductive members of the switchgear during and after fault interruption. Screws made of non-conducting material and insulating barriers shall be provided for all surfaces exposed to ionized gases. Metal screws covered with insulating caps are not acceptable. Insulation of circuit breaker compartment and its vent openings are not required if the Contractor can prove to the satisfaction of the Engineer that the gases exhausted from the circuit breaker removable element during fault interruption are completely deionized.

8. Vent openings shall be designed to prevent damage to or malfunctioning of the circuit breaker, control circuits and other components from foreign objects and shall be so located that hot gases or other materials cannot be discharged through them in a manner which might be injurious to operating personnel. Each circuit breaker housing shall be provided with protective shutters which close and block access to the positive bus and breaker load terminals as the removable element of circuit breaker is racked from the cubicle. Protective shutter mechanism shall be designed and installed in a manner that it can be removed for repair without necessitating de-energization of the main bus.

9. Rectifier main DC breaker housings and bus entry unit housings shall be of sufficient strength to support the DC cathode bus duct which interconnects the DC switchgear with the rectifier.

10. The width of individual switchgear units shall be approximately 24 inches but in no case shall exceed 26 inches for the rectifier main breakers and the feeder breakers; 30 inches for the auxiliary unit and

18 inches for the bus entry units. Width of circuit breaker units shall not be less than 23 inches.

11. The switchgear shall be secured to the insulated epoxy floor with approved insulated anchors.

12. Circuit breaker housings shall be designed for easy racking of breakers into and out of the cubicle. Cubicles are to be designed so that doors attached to circuit breaker removable elements have ample clearance from extended upper control compartments.

13. Finish of inside and outside of switchgear assembly, including all steel panels and subpanels inside the cubicles, shall be in accordance with Article 1.16, Section 16203. Galvanized, unpainted steel panels are not acceptable.

C. Buses and Bus Connections

1. Main bus and bus taps of the switchgear shall be of copper and shall be provided in accordance with Article 1.06, Section 16203. Continuous current carrying capacity of buses and bus taps shall be as specified in Article 2.06.N, this Section.

2. Main bus and bus taps shall be supported and braced to withstand short circuit stresses as great as those for which circuit breakers are designed.

3. The buses shall be supported on high-strength flame retardant polyester glass, porcelain, or approved equal insulators designed to ensure adequate electrical clearances and to withstand the specified mechanical stresses.

D. DC Power Circuit Breakers

1. Circuit breakers shall be 750-volt DC class minimum, single pole, air break, draw-out type without negative disconnecting device, capable of withstanding a continuous no load or light load voltage of 750 volts DC. The breakers shall be of high speed classification as per ANSI Standard C37.16, suitable for operating on a system load bus supplied directly from two 3,000 kW DC rectifiers operated in parallel, and as specified below. The full load rectifier voltage will initially be 590 volts, increased to 650 volts in the future. Contractor is hereby informed that application of reactors between the rectifiers and DC switchgear or between the rectifiers and negative equalizer bus, to limit the short circuit current seen by the circuit breakers, will not be acceptable.

2. The DC circuit breakers shall have peak current, momentary current, short time current and short circuit current ratings required for operation in a substation with two 3,000 kW rectifiers of the type specified in Article 2.05, this Section, in operation, when supplied

from a 13.8 kV, 60 Hz system capable of delivering 600 MVA with an X/R ratio of 10. For rating the rectifier and traction feeder circuit breakers, Contractor shall add 50% to the peak current and sustained current values thus obtained. Short circuits specified herein are those that are applied to the load terminals of either traction feeder circuit breaker or rectifier main DC circuit breaker and to the load terminals (negative) of the rectifiers.

a. High speed DC circuit breakers which limit peak value of short circuit current shall have short circuit interrupting capability equal to or greater than the maximum available rate of rise of short circuit current under the short circuit conditions specified. The short circuit interrupting rating of the circuit breaker with delayed tripping shall not be less than 100,000 amperes.

b. The rectifier main DC circuit breakers shall either be capable of withstanding a fault on the 590 volts or 650 volts DC bus until AC relays trip the rectifier transformer feeder breaker at the AC switchgear or a tripping device which fully coordinates with all other specified coordination requirements may be supplied, if approved by the Engineer, which shall protect the circuit breaker from damage under bus fault conditions.

c. The rectifier main DC circuit breakers shall have momentary current rating which is equal to or greater than the maximum available peak circuit breaker current with a short circuit at the load terminals of the circuit breaker.

d. The rectifier main DC circuit breakers shall have short time current rating which is equal to or greater than the maximum rms value of available circuit breaker current during a period of 250 milliseconds following application of short circuit to the load terminals of the circuit breaker. The rated short time current is defined as the designated limit of available rms current which the circuit breaker can carry for a period of 250 milliseconds, without impairing the circuit breaker's ability to meet all other ratings.

e. High speed DC feeder circuit breakers which limit peak value of short circuit current with fastest-acting tripping arrangement provided shall have a momentary rating no less than 125,000 amperes.

f. All DC circuit breakers shall be rated to successfully dissipate the maximum value of energy stored in the system inductance during circuit breaker arcing under the short circuit conditions specified. Breaker maximum arc voltage shall not exceed 75% of the peak reverse voltage (PRV) of diodes furnished with the rectifiers and the limits dictated by DC power and control equipment.

3. Circuit breaker operating mechanism shall be of the mechanically latched or the magnetically latched type, solenoid operated or spring stored energy operated, as specified below, and shall be electrically and mechanically trip free. The control circuits of all breakers shall be provided with anti-pumping protection.

   a. The closing coil of solenoid operated circuit breakers shall be rated for operation on 125 volt DC, supplied from the substation battery. Circuit shall be provided with a timing relay for closing coil cut-off. The closing coil shall successfully close the breaker over a voltage range of 90 to 140 volts DC.

   b. All solenoid operated circuit breakers shall have trip circuit rated 125 volt DC supplied from the station battery and shall be capable of tripping the breaker over a voltage range of 70 to 140 volts.

   c. The mechanism of stored energy operated circuit breakers shall be rated for operation on 125 volts DC and shall successfully close the breaker over a voltage range of 90 to 140 volts and trip the breaker over a range of 70 to 140 volts. The 125-volt DC close and trip circuits will be supplied from the substation battery.

   d. DC circuit breakers shall be designed so that they may be safely closed and tripped manually in the operating position during an emergency. Removable, fully insulated handles shall be provided for manual closing. Mechanical interlocks shall be provided which will disable the manual closing mechanism if the breaker compartment door is open. Manual trip shall be from an approved mechanical trip device.

   e. The operating mechanism of each circuit breaker shall be provided with a mechanical breaker contact position indicator.

4. Breaker tripping devices shall be furnished as required to provide reliable coordinated protection for the system. They shall have operating characteristics and adjustable ranges as outlined in Article 2.02.D, this Section. Range of trip settings shall be as specified and calibration scales shall be calibrated covering full range of adjustable settings.

   a. Mechanically latched DC circuit breakers shall be provided with an undervoltage trip device which is magnetically held by flux produced by control power current and which mechanically trips the circuit breaker upon reduction of control power voltage to any level, which does not allow reliable operation.

   b. Mechanically latched DC circuit breakers, which require control power for any part of an instantaneous overcurrent or reverse current trip arrangement shall be provided with a second

overcurrent or reverse current trip arrangement. The redundant instantaneous overcurrent or reverse current trip arrangements shall independently sense magnitude of the circuit breaker current and may utilize control power for their tripping but shall have their own separate electrical components and not share any common electrical components with the first overcurrent or reverse current arrangement. One of the two tripping arrangements may utilize the undervoltage trip device to affect circuit breaker tripping. The discriminating rate-of-rise trip equipment will not be acceptable as the second tripping arrangement specified above. However, the discriminating rate-of-rise trip equipment may utilize a current sensor and trip coil in common with either of the required redundant instantaneous overcurrent or reverse current trip arrangements and may utilize the undervoltage trip device to affect circuit breaker tripping. Each of the redundant instantaneous overcurrent or reverse current trip arrangements shall provide the overall coordination specified in Article 2.02.D, this Section.

- For the rectifier main DC circuit breaker, the second reverse current tripping arrangement may be a polarized electromechanical trip device, a current sensing polarized relay, which shunt trips or undervoltage trips the circuit breaker, or other arrangement in conformance with this Specification, which is approved by the Engineer.
- For the DC feeder circuit breaker the required second overcurrent tripping arrangement may be an electromechanical trip device, a current magnitude sensing non-polarized relay, which shunt trips or undervoltage trips the circuit breaker, or other arrangement, which is approved by the Engineer. Tripping for the redundant overcurrent arrangement shall be adjustable within the limits of 100% and 400% of the rating of direct acting instantaneous series trip device specified for the feeder circuit breakers.

c. Circuit breakers, which are magnetically latched, shall be latched by flux produced from control power and tripped by interaction between this flux and flux produced by circuit breaker primary current. No undervoltage trip device is required.

- For the rectifier main DC circuit breakers, the magnitude of latch flux shall be at least 200% of the minimum value required for successful closing of the circuit breaker without primary current. The circuit breaker tripping arrangement may be responsive to rate-of-rise of reverse current by use of inductive shunts or other means. Control power current for the magnetic latch shall not exceed 500 milliamperes.
- For the DC feeder circuit breakers, the magnitude of latch flux shall be such that at least 30,000 amperes of primary current are required to cause tripping by shift of flux. The circuit breaker tripping arrangement shall not be responsive to rate-of-rise of

primary current. Control power current for the magnetic latch shall not exceed 500 milliamperes. DC feeder circuit breakers shall be provided with a second tripping arrangement which is easily adjustable to cause tripping between the limits of 100% and 400% of the rating of direct acting instantaneous series trip device specified for the breaker. This second tripping arrangement may be an electromechanical trip device which mechanically or electrically trips the circuit breaker, a current magnitude sensing non-polarized relay which shunt trips the circuit breaker, or other arrangement in conformance with this Specification which is approved by the Engineer. The rate-of-rise discrimination equipment will not be acceptable as the second tripping arrangement specified above, but may utilize a common trip coil.

5. Each circuit breaker shall be mounted on a mobile steel frame equipped with power and control circuit disconnecting devices, to make the circuit breaker and the operating mechanism a removable element. The frame shall be permanently attached to the circuit breaker and shall be equipped with wheels for rolling the breaker on the floor of the substation. *All DC circuit breakers are required to be a "direct roll-in" design which allows moving the breaker over the concrete substation floor into the switchgear unit, and vice versa, without the need for portable ramps or wedges*. A four-digit register type operations counter shall be mounted on the removable element of each circuit breaker.

6. The power disconnecting devices shall consist of self-aligned assemblies. Female contacts shall be constructed of bridging segments designed to ensure high pressure contact guaranteed not to distort or fail under the mechanical stresses and heating due to duties specified for the circuit breakers.

7. The control disconnecting devices shall provide connections for the control circuits and interlocks between the removable element and the housing. The devices shall be accurately located and securely mounted to maintain alignment.

8. Circuit breaker components requiring periodic maintenance and replacement and those, which may require replacement due to deterioration, shall be easily accessible without removal of major breaker assemblies.

9. Frames of relays and other devices mounted on energized breaker frame and operated on 125 volts DC shall be insulated for 1,000 volts DC from the frame of the circuit breaker. Relays, switches, terminal blocks and other components of the control circuitry on the breaker shall be labeled as identified on Contractor's prepared and Engineer's approved shop drawings.

10. In addition to auxiliary switches required for control, interlock,

indication and alarm circuits, each circuit breaker shall be furnished with a minimum of four "a" and four "b" spare auxiliary switch contacts, wired to outgoing wiring terminal block for Authority's use.

11. Normally closed auxiliary switches mounted on the removable element and used for interlocking shall be shunted with truck-operated cell switches to permit operation of interlocked equipment when breaker is in the withdrawn position. A minimum of two "a" and two "b" spare cell switch contacts shall be provided, wired to outgoing wiring terminal block for Authority's use.

12. All auxiliary switches, whether cell mounted or mounted on removable element, and breaker control circuit wiring connected through control disconnecting devices shall be made up and operable when breaker is racked to the test position so that the breaker may be closed and tripped electrically or mechanically with power disconnecting devices open.

13. Rectifier main DC circuit breakers shall be mechanically and electrically interchangeable with each other.

14. DC traction feeder circuit breakers shall be mechanically and electrically interchangeable with all other traction feeder breakers of the same ratings.

15. Main rectifier DC circuit breakers shall not be interchangeable with DC traction feeder circuit breakers.

16. A mechanical or electrical indicator shall be provided at the front of the breaker compartment to show that the breaker is in the "test" or "connected" position. An electrical breaker position indicator is acceptable.

17. Each circuit breaker unit shall be equipped with a cranking device for moving the removable breaker element to and from its operating position. The mechanism shall be mechanically operated by a hand crank, arranged to rack the breaker from test to operating position, also from disconnect to test position. Suitable guide rails shall be provided for centering the breaker in proper position when inserting or withdrawing the removable element. Front ends of guide rails shall be flared and the bottom plate of the enclosure within the guide rails beveled to facilitate the lining-up and insertion of the circuit breaker removable element. A positive stop shall be provided to prevent over-travel of the removable element when moving it into operating position. A similar positive stop shall be provided for the test position. The design of the circuit breaker unit having the access door mounted on the stationary structure of the switchgear shall permit closing of the compartment door with the circuit breaker in test position.

18. Mechanical interlocks shall be provided on each circuit breaker to

prevent the withdrawal of the removable element when the breaker is in the closed position and to prevent the insertion of a closed breaker from the test to the operating position. For circuit breakers with stored energy type operating mechanism, the interlocks shall also discharge the springs before the breaker removable element can be fully withdrawn from its housing. Breaker must be arranged so that personnel are guarded from contact with energized parts while racking the circuit breaker into or out of the connected position.

19. Rectifier main DC circuit breakers shall be key-interlocked with the negative disconnect switch of the respective rectifier, arranged to prevent closing or opening of the disconnect switch unless the main DC circuit breaker is in fully disconnected position, as specified in Article 1.14, Section 16203.

E. Arrangement of Control Devices

1. Normal control, indicating and protective devices associated with the circuit breaker operation shall be mounted in their respective DC breaker switchgear compartments, except as otherwise specified. All devices, whether mounted on the compartment door or other portion of the stationary unit structure, must be physically accessible and so connected as to permit testing and maintenance of relays and control circuitry in de-energized condition while the circuit breaker is in normal operating position. The arrangement of devices will be subject to approval of the Engineer. Insulated panels attached to cutouts in the doors for mounting of relays, switches and devices, are not acceptable. Individual cutouts shall be provided for mounting each relay, switch and device.

2. Current shunts, transducers and other such equipment shall be accessible for testing and maintenance with the bus of switchgear energized.

3. Care should be taken in arrangement of relays, control and key-operated switches, indicating lights and instruments so as not to violate the provision for the removal of adjacent breaker when the door of adjacent unit is opened to 90˚. Refer to Article 2.06.B, this Section.

F. Power Circuit Terminations

1. Rectifier main DC circuit breaker units shall be arranged for direct bolted connections to incoming DC positive cathode bus specified in Article 2.07, this Section, using copper bus bars. All contact surfaces shall be silver plated. Buses and connections shall conform to Article 1.06, Section 16203. The bus connections shall be arranged for top entrance. Arrangement of buses will be determined at the Design Conference.

2. For each DC traction feeder, the Contractor shall furnish four bolted

type heavy-duty terminal lugs suitable for stranded copper feeder cables of sizes shown on Contract Plans, entering from below. Terminal lugs shall be provided in accordance with Article 1.07, Section 16203, and shall have four-bolt tongue with NEMA standard spacing. Provisions shall be made for quick disconnection and isolation of each cable from the terminal during an emergency without disturbing the remaining cables. This requires access to the terminals through an easily opened hinged panel and sturdy, individual support for each cable close to the connection point. Back-to-back arrangement of terminal lugs will not be acceptable.

G. Wiring and Terminal Blocks

1. Secondary and control wiring in each unit, including that on removable element, shall be No. 12 AWG or larger, stranded tinned copper in accordance with Article 1.09, Section 16203, and insulated for 1,000 volt DC service.

2. Circuits requiring external connections shall be factory-wired to readily accessible terminal blocks, within the control compartments for connection to field wiring entering from above. Provide terminal blocks rated at 1,000 volts DC and in accordance with Article 1.09, Section 16203.

3. All elements of control devices operated on 650 volts DC shall be connected with red-colored wire. Associated terminals at equipment and devices shall be insulated for 1,000 volts from adjacent terminals and from the frame of switchgear. Exposed terminals shall be capped or provided with insulating covers to prevent accidental contact by operating and maintenance personnel.

H. Control Sources

1. An ungrounded, two wire, 125 volt DC control bus shall be provided integral with the switchgear assembly. The control bus shall be not less than No. 4 AWG consisting of stranded switchboard wire, wired to suitable screw type terminal blocks in the auxiliary compartment for connection to No. 2 AWG supply conductors. Each circuit breaker control circuit shall be supplied from this bus through individual switches and fuses. In addition, the closing circuit and spring loading motor circuit of each stored energy operated circuit breaker shall be protected by a secondary set of fuses to prevent opening of main fuses and thus loss of trip supply on closing circuit or motor circuit faults. All fuses, fuse holders and switches shall be rated for 1,000 volts DC service.

2. A two wire, 120 volt, 60 Hz control bus, fed from the static inverter-transfer switch package specified below, shall be provided integral with the switchgear assembly for reliable supply to load measuring circuit motor-operated timers, Device 102, rectifier and DC switchgear ground detection relays, Devices 64R, 64RX, 164S and

164SX, rectifier heat sink overtemperature device circuits, transducers and other control devices requiring AC supply. The 120-volt AC control bus shall be not less than No. 10 AWG stranded switchboard wire. Both legs of each take-off from this bus shall be separately fused. The reliable supply bus shall be factory-wired to the static transfer switch, Device 83, in the auxiliary compartment. The normal source terminals of the static transfer switch shall be factory-wired to terminal blocks in the auxiliary compartment for connection to the 120 volt, 60 Hz supply conductors. The standby source terminals of the static transfer switch shall be factory-wired to the load side terminals of the inverter in the auxiliary compartment. The inverter shall be supplied from the 125 volt DC control bus of the switchgear through a set of fuses. The 120 volt AC reliable supply control bus shall be wired to suitable terminal blocks at each of the end cubicles of the switchgear to facilitate addition of future switchgear units. The No. 10 AWG conductors of the normal 120 volt supply will enter the auxiliary unit from above.

3. The static inverter/transfer switch package shall contain the following:

   a. A static inverter, rated as specified in Article 2.06.N, this Section, having an output of 115 volt, 60 Hz sine wave of one percent accuracy with less than five percent harmonic content under no load and any of the loading conditions.
   b. A static transfer switch to automatically transfer the AC load from the normal 115 volt, 60 Hz source from the 120/208V distribution panel to the standby source upon failure of the normal source. Retransfer to normal source shall take place automatically on restoration of normal source after a time delay having an adjustable range of 5 through 50 seconds. The control circuitry of the static transfer switch shall be arranged for operation on both the normal supply and the standby supply to assure an output with either supply energized.
   c. A push button in the normal supply circuit to simulate power failure and thus effect transfer to standby inverter supply for testing purposes, mounted on the door of the switchgear auxiliary compartment.
   d. Reliable 115 volt AC supply undervoltage relay, Device 127, connected to the load side of the static inverter/transfer switch package for local annunciator.
   e. Overload and short circuit protective devices.
   f. A voltmeter and an ammeter connected on the load side of the static inverter/transfer switch package, to be mounted on the door of the switchgear auxiliary compartment.
   g. Indicating lights mounted on the door of the switchgear auxiliary compartment indicating whether normal or standby supply is in use.
   h. Three auxiliary contacts which close on transfer from normal to standby position, time delayed to override the clearing time of the load fuse, for local annunciator and for remote indication via

the Authority's supervisory systems:

4. All fuses used for control shall be of the cartridge type of appropriate rating, conforming to Article 1.10.F, Section 16203. All necessary fuses shall be furnished with the equipment. In addition, a minimum of 10%, but not less that two fuses of each rating shall be furnished with the switchgear assembly.

5. The static inverter-transfer switch package shall be submitted to the Engineer for approval.

I. Special Requirements:

1. Each separate compartment within a switchgear cubicle shall be provided with an electric strip heater of adequate size to prevent condensation within the compartment. All heaters installed in a switchgear cubicle shall be monitored by means of an ammeter scaled and marked for the heater load. Each individual heater circuit shall be provided with an indicating light with blue lens to indicate operation of the heater and an ON-OFF switch. Heaters shall be provided with properly designed guards to protect operating personnel against accidental contact with hot surfaces.

2. A fluorescent lighting fixture with conveniently located and properly labeled toggle switch or a door operated switch, rated 250 volts, minimum, shall be provided in each compartment of the switchgear which contains relays, control devices and outgoing wiring terminal blocks. Incandescent lighting will be acceptable only for compartments where, in the opinion of the Engineer, the installation of fluorescent lighting fixture would be impractical. In addition, a duplex receptacle, rated 250 volts, 20 amperes minimum, shall be provided in each switchgear unit, connected for 120 volt service. The outlet boxes of light receptacles, light switches and plug receptacle shall be insulated from switchgear enclosure for a minimum of 1,000 volts DC.

3. A three phase, four wire, 120/208 volt, 60 Hz supply bus shall be provided throughout switchgear lineup. The AC supply bus shall be not less than No. 8 AWG, stranded switchboard wire. The heater, light and receptacle circuits shall be supplied from this bus through fusible pullout disconnects with cartridge-type fuses located in each switchgear unit. The fuse holders shall be insulated from switchgear enclosure for 1,000 volts DC. All necessary fuses shall be furnished with the equipment. In addition, a minimum of 10%, but not less than two, spare fuses of each rating shall be furnished. As far as practicable, the loads shall be balances between the phases of the supply bus. The supply shall be wired to screw type terminal blocks, insulated from the switchgear enclosure for 1,00 volts DC, located in the auxiliary compartment of the switchgear lineup for top connection to No. 6 AWG supply conductors.

J. Nameplates

1. Nameplates shall be provided in accordance with Article 1.08, Section 16203. The legend of nameplates shall be submitted to the Engineer for approval.

2. Switchgear identification nameplate shall be engraved: "750 VOLT DC SWITCHGEAR".

K. Supervisory Control Requirements

The DC switchgear assembly shall be provided with supervisory control, indication, measuring and interface devices as specified in Article 2.02.C, Paragraph 5, this Section.

L. Circuit Breaker Test Cabinet

1. Contractor shall provide a wall-mounted test cabinet for electrical operation of circuit breakers at location remote from the switchgear. The test cabinet shall include a control switch, similar to that furnished with the switchgear, to close and trip the breaker; red and green breaker position indicating lights; ten feet of control cable with a connector at the end for connection to the breaker; a set of properly sized fuses to protect the control circuit and screw-type terminals for No. 8 AWG conductors of 125 volt DC control supply. An additional indicating light with white lens shall be provided for monitoring the control supply.

2. The control switch and indicating lights shall be mounted on the door of the test cabinet. The wiring and terminal blocks shall be provided in accordance with Article 1.09, and the nameplates with Article 1.08, Section 16203.

3. A proper connector shall be provided for protecting the control cable at the point of entry. Provisions shall be made for storing or racking the control cable and the connector at the test cabinet.

4. The test cabinet shall be finished inside and out in accordance with Article 1.16, Section 16203.

M. Accessories

1. Contractor shall furnish special tools and equipment-handling devices as recommended by the manufacturer for installation, assembly, adjustment and maintenance of the DC switchgear and circuit breakers furnished. Special tools are defined as tools not readily available on the open market. All items shall be furnished as part of the initial delivery of the switchgear equipment.

2. Contractor shall also furnish and ship with the switchgear auxiliary equipment and accessories necessary for operation, maintenance, testing and handling of removable components outside the switchgear

assembly. These shall include, but not be limited to, the following:

1 - Circuit breaker test cabinet, as specified in Article 2.06.L., this Section.
1 - Floor-mounting steel cabinet with hinged doors with three-point latching mechanism and key-locking handle and shelves, for storing tools and accessories. Cabinet shall be fully rustproofed and finished in light gray enamel.
1 - "Fifth-wheel" device for handling breaker outside its housing.
2 - Racking-in cranks
1 - Manual spring charging handle (if required)
1 - Insulated level for manual closing of the breaker
1 - Arc chute lifting device
1 - Set of tools required for breaker maintenance
1 - Set of insulated anchor blocks for the DC switchgear assembly. These shall be shipped in advance of equipment.
2 - One-quart cans of matching touch-up paint

N. Detailed Equipment Requirements

Contractor shall furnish and deliver to the substation the 750-volt DC switchgear assembly consisting of switchgear units of the type and quantity specified below. The individual units in the assembly shall be arranged to form a lineup shown on Contract Plans.

Individual switchgear units shall consist of the equipment, devices and appurtenances of the types and quantities detailed below.

1. Rectifier DC Main Breaker, Device 72R

2 - 750 volt rectifier DC main circuit breaker units, each including, but not be limited to, the following:
1 - Metal-enclosed stationary unit with 10,000-ampere bus and 8,000-ampere tap equipped with provisions for connection to 8,000 ampere DC positive cathode bus entering from above.
1 - 8,000 ampere air circuit breaker removable element with direct acting series reverse current instantaneous trip device, Device 32, as specified in Article 2.06.D, this Section, set a minimum value consistent with overall coordination of rectifier circuit protective devices. The reverse current devices shall be provided with auxiliary contacts for operation of auxiliary relay, Device 32PX, which shall be used for remote indication and lockout relay operation.
1 - Removable element position switch with a minimum of four convertible contacts.
1 - 8,000 ampere, 50-millivolt shunt with indicating ammeter, 0-15 kA scale, and calibrated leads.
1 - Watt transducer, rated for voltage input of 0 to 750 volts DC, current input of 0 - 50 millivolts DC from shunt, having an output in milliamperes DC linearly proportional to the input, for station recording wattmeter, Device W-XD.
1 - Isolation amplifier. Input from 8,000 ampere, 50 millivolt shunt,

for telemetering rectifier current, Device IA.
1 - DC indicating voltmeter, 0-750 volt scale, connected to rectifier side of breaker.
1 - Control switch "TRIP-CLOSE" for closing and tripping the main DC breaker, with green, white (if breaker has stored energy type operating mechanism) and red indicating lights, Device 101.
1 - Control switch "TRIP-CLOSE" for closing and tripping the rectifier AC breaker, with green and red indicating lights, Device 1.
1 - Breaker control mode selector switch "LOCAL-OFF-SUPV" for rectifier AC circuit breaker, Device 43.
1- Master control relay, electrically reset type, Device 4
1- Set of space heaters with "ON-OFF" switch, blue indicating light and ammeter as specified.
1- Set of DC and AC control power disconnect devices with fuses.
1- Key interlock system as described in Article 1.14, Section 16203.
1- Lot nameplates as specified.

2. DC Traction Feeder Breaker, Device 172

8 - 750 volt DC automatic reclosing traction feeder circuit breaker units, each including, but not be limited to, the following:
1 - Metal-enclosed stationary unit with 10,000-ampere bus and 4,000-ampere tap
1 - 4,000 ampere air circuit breaker removable element with direct acting series bi-directional instantaneous trip device, Device 176. The continuous current rating of the series trip device shall be 4,000 amperes; the instantaneous trip device shall be adjustable between 100% and 400% of the continuous rating, with calibration marks at suitable intervals.
2 - Interposing relays, to close and trip the circuit breaker via supervisory, with 125 volt DC coil, Devices 201C and 201T.
1 - Removable element position switch with a minimum of four convertible contacts.
1 - 4,000 ampere, 50 millivolt shunt with calibrated leads for providing input to instantaneous overcurrent relay Device 176F, rate-of-rise relay, Device 150F, ammeter and isolation amplifier, Device IA.
1 - Bi-directional instantaneous overcurrent relay with an adjustable range of 4,000-0-12,000 amperes, to operate from 4,000 ampere, 50 millivolt shunt, Device 176F.
1 - Timing relay, time delay on pickup, adjustable between 5 and 50 seconds and calibrated in seconds, to operate in conjunction with Device 176F, for operation on 125 volts DC, Device 176FX.
1 - Polarized discriminating overcurrent tip device or rate-of-rise overcurrent trip device, to operate from 4,000 ampere, 50 millivolt shunt, Device 150F, capable of discriminating between remote short circuits on the track and inrush current of starting trains.
1 - Auxiliary relay, to operate in conjunction with Device 150F, for operation on 125 volts DC, Device 150FX
1 - Auxiliary relay, to operate in conjunction with Device 176, for operation on 125 volts DC, Device 176X.

1 - Zero-center scale ammeter for operation with 4,000 ampere, 50-millivolt shunt as specified. Ammeter scale shall be 4,000-0-8,000 amperes.
1 - Isolation amplifier as specified. Input from 4,000 ampere, 50 millivolt shunt, for telemetering DC feeder current. Device IA.
1 - DC indicating voltmeter, 0-750 volt scale.
1 - Voltmeter switch "FEEDER-OFF-BUS", connecting the DC voltmeter to either cable side or bus side of the breaker.
1 - Permissive setup relay, electrically reset type, to start the closing/reclosing cycle of the DC traction feeder circuit breaker; operating coil and closing coil both rated 125 volts DC, Device 169.
1 - Set of load measuring, voltage measuring and automatic reclosing equipment, as specified in Article 1.05.C, this Section, to prevent closing of the circuit breaker to a faulted circuit. The equipment shall include a load measuring relay, Device 182, a voltage measuring relay, Device 183, a set of load measuring resistor and contactor, Device 129, a cycle timer, Device 102 and all necessary accessories. The cycle time shall be synchronous motor driven, cam-operated type for operation on 120 volt, 60 hertz reliable AC supply. Load measuring resistor shall be located on top of feeder breaker stationary unit and shall be provided with ventilated enclosure. Contractor shall provide the interconnecting wire and insulated resistor supports.
1 - Control switch "TRIP-CLOSE" for closing and tripping the DC traction feeder breaker, with green, white (if breaker has stored energy type operating mechanism) and red indicating lights, Device 101.
1 - Breaker control mode selector switch "LOCAL-OFF-SUPV", Device 143.
2 - Instantaneous voltage relays for "Feeder Energized" indication, Device 197X, minimum range 400-750 volts DC, complete with voltage dropping resistor.
1 - Set of four heavy duty terminal lugs suitable for 2,000-kcmil standard copper feeder conductor mounted on the load terminals for the DC traction feeder breaker, for traction feeder cables entering from below.
1 - Load measuring system bypass switch and associated timing relay.
1 - Surge arrester, rated for 750 volts DC service, connected to line side of circuit breaker.
1 - Set of space heaters with blue indicating light, ON-OFF switch and ammeter.
1 - Set of DC and AC control power disconnect devices with fuses.
1 - Lot of nameplates as specified

3. 750 volt DC Switchgear Auxiliary Unit

1 - 750 volt DC switchgear auxiliary unit, including, but not be limited to, the following:
1 - Metal-enclosed stationary unit with 10,000-ampere bus
1 - Set of ground detector circuit components, including relays, Devices 164S, 164SX, DC power supply and related devices, as

detailed in Article 2.02.C, this Section.
1 - Lot of alarm bell, timing relay, Device 74 and illuminated warning sign "SWITCHGEAR FRAME ALIVE" as specified in Article 2.02.C, rated for operation on 120 volt, 60 hertz.
1 - 125 volt DC to 120 volt 60 Hz inverter and an automatic transfer switch, Device 83, employing solid-state circuitry, for reliable 120 volt AC supply for all DC traction feeder timing relays, transducers, rectifier heat sink over-temperature detectors and certain rectifier accessories as specified in Article 2.05, this Section, rectifier and DC switchgear ground detection relays, and other control devices requiring AC power supply. The inverter and the transfer switch shall be rated to carry continuously the load of all these devices and an additional load of Authority's remote devices of 100 volt amperes. An ammeter and voltmeter of appropriate scales, indication lights and a test push button shall be provided for the 120 volt reliable supply.
1 - 120 volt reliable AC supply undervoltage relay, for operation on 120 volts, 60 Hz, Device 127.
1 - DC power supply with adjustable 15-25 volt output, as specified, for isolation amplifiers, Device IA, supplied from the reliable 120 volt AC control bus.
1 - Recording wattmeter, strip chart type, suitable for totalizing two separate inputs from rectifier watt transducers. Scale shall be as indicated on Contract Plans.
1 - Recording voltmeter, strip chart type, to record the DC switchgear bus voltage. Scale shall be 0-750 volts.
1 - Voltage transducer, as specified, for telemetering, 750 volt DC switchgear bus potential, Device V-XD.
1 - Set of space heaters with ON-OFF switch, blue indicating light and ammeter as specified.
1 - Lot nameplates as specified.

0.7 ANODE AND CATHODE BUSES

A. General

1. AC anode bus ducts and DC positive and negative cathode bus ducts shall be furnished for interconnection of the rectifier transformer, rectifier, the DC switchgear, and the negative equalizer bus and drainage board. Contract Plans indicate the desired arrangement of bus ducts. At the Design Conference, Contractor shall bring to Engineer’s attention and approval all deviations he plans to make from the arrangement shown.

2. For each rectifier package, the following type of bus ducts shall be furnished:

   a. 600 volt AC non-segregated phase anode bus duct assembly for connecting the rectifier transformer to the rectifier.
   b. 750 volt DC positive cathode bus duct assembly for connecting the rectifier positive terminal to the DC switchgear.
   c. 750 volt DC negative cathode bus duct assembly for connecting

the rectifier negative terminal to the negative equalizer bus and drainage board.

B. Assembly Requirements

1. Metal Enclosure

   a. Each bus duct assembly shall be metal enclosed, ventilated, non-segregated phase type, conforming to ANSI C37.20, except that an approved low impedance type bus duct may be applied as the anode bus, providing such requirement is dictated by the design of the transformer and rectifier package. The enclosure shall be fabricated from aluminum as specified. Removable covers shall be provided to allow access to bolted bus connections and insulators for cleaning and inspection. Removable covers shall be secured with bolts to the frame. *All screening material for ventilation openings shall be tack welded to the outside surface of the bus duct to minimize the potential for screening material to fall into the bus duct if struck accidentally.*
   b. Metal enclosures shall be finished in accordance with Article 1.16, Section 16203. Two quarts of matching touch-up paint shall be shipped with the bus duct assemblies.

2. Copper Bus Bars

   a. Bus bars shall be of high conductivity rectangular copper with round edges finished to required size by cold rolling or drawing. Bus bars shall have uniform shape and dimensions, free from defects in material and workmanship. Bus bars shall be individually insulated, properly supported and braced to each other and to the enclosure with approved, high quality, high strength, non tracking insulators to withstand short circuit stresses to be encountered in use. All bus taps and connections shall be tightly bolted. Contract surfaces of bolted joints shall be factory silver plated. Busbars, joints and hardware shall conform to Article 1.06, Section 16203.
   b. Bus bars shall be rated for current and voltages specified for individual applications. They shall be amply designed for continuous operation at the rated load conditions.
   c. The temperature rise of bus bars at the hottest spot for the specified duty shall not exceed 65˚C over an ambient of 40˚C, thus limiting the maximum operating temperature of bus conductor to 105˚C.

3. Lengths and Fittings

   a. Bus duct assemblies shall be supplied complete with connection flanges, taps, elbows, insulated housing sections, offsets, splicing plates, terminal connectors, and associated accessories. Bus duct assemblies shall be furnished in accordance with the arrangement, dimensions and details depicted on final,

Engineer's approved shop drawings.

b. The shipping sections shall be pre-assembled in the factory so that minimum installation is required at site. It is the responsibility of the Contractor to furnish the equipment as specified here and shown on the Contract Plans so that they can be installed as a system without any modifications or requiring additional materials and labor at site, except to carry out the manufacturer's installation instructions.

4. Hardware and Supports

a. All hardware required to make the field connections between sections and terminations to the equipment shall be furnished in sufficient quantity.

b. Supports required for bus ducts shall be hanger type. Location of supports shall be shown on Contractor's equipment arrangement drawings and are subject to Engineer's approval. Supports of positive cathode buses shall be provided with approved insulators to insulate the bus enclosure from building structure for a minimum of 1,000 volts DC.

5. Expansion Joints

Expansion joints shall be provided by the Contractor wherever required for proper operation of the equipment.

6. Induced Heating

Bus ducts are intended for operation at high value of currents as specified for each type. The design of bus ducts shall be such as to minimize the induced magnetic heating and induced circulating currents in the metallic enclosure of the bus duct, adjacent enclosures and supporting structures.

7. Insulated Sections

Insulated sections of bus duct housing, where shown on the Contract Plans, shall be designed for phase-to-ground potential existing in these sections. The material and detailed design of insulated sections are subject to Engineer's approval.

C. 600 Volt AC Anode Bus Duct Assemblies

1. The 600 volt AC anode bus duct assemblies shall meet all the applicable requirements of Article 2.07.B above, conform to ANSI C37.20 and meet the following additional requirements:

a. Rated maximum voltage: 635 volt, maximum
600 volts, nominal

b. Rated insulation level power frequency withstand: 2.2 kV (for one minute, dry)

2. Buses shall be rated to carry continuously the current of associated rectifier transformer and rectifier operated at 160% of rated full load.

The temperature of the bus bars shall not exceed maximum limit of 105˚C under these loading conditions. The bus duct assembly shall be compatible in design and construction with the provisions made at the transformer and rectifier and shall operate as an integral unit when assembled.

3. Enclosure of bus duct assemblies shall be ventilated, made of high strength, corrosion-resistant aluminum. Anode bus with steel enclosure may be acceptable if the Contractor can prove to the satisfaction of the Engineer that the induced magnetic heating will not increase the temperature of the enclosure above safe limits during the two hour overload cycle specified in Article 2.05.D, this Section, for the rectifier.

4. A single bus duct assembly containing the conductors from both secondary windings of transformer shall be provided, as shown on Contract Plans. Contractor may furnish two separate anode bus ducts, one from each secondary windings of the transformer, only upon the approval of the Engineer.

5. Each anode bus duct assembly shall be provided with bus taps, rated not less than 1/3 of the continuous current rating of the main bus to enable connection of future bus ducts for harmonic suppression filters with minimum of labor and without involving drilling of main bus bars.

6. Grounded bus enclosure(s) shall be insulated from the high-resistance grounded rectifier enclosure by installation of boxed micarta or fiberglass section in the vertical portion at the rectifier, providing a minimum of six inches clearance between the metal enclosure of bus duct and nearest metal on rectifier. Alternate arrangement is insulated section in horizontal bus run near the rectifier, providing a minimum of two feet clearance between the metal bus enclosure and the nearest metal connected to the rectifier enclosure.

7. Suitable support of bus enclosures shall be provided as may be required to ensure rigid structure and workmanlike installation of the system.

8. The bus conductors, because of the inherent characteristics of the circuit, remain at a DC potential relative to the bus enclosure while energized. Construction of the bus duct and the materials used shall be proper for this type of service.

9. At both transformer and rectifier, flexible bus conductor terminations shall be provided. The termination details shall be fully coordinated with the rectifier transformer specified in Article 2.04 and rectifier in Article 2.05, this Section.

D. DC Positive and Negative Cathode Bus Duct Assemblies

1. DC cathode bus duct assemblies shall meet all the applicable requirements of Paragraph 2.07.B., above, and conform to ANSI C37.20 and shall meet the following additional requirements:

   a. Rated maximum voltage: 750 volts
   b. Rated continuous current: 8,000 ampere

2. Cathode bus duct assemblies shall be rated to carry continuously the current of associated rectifier operating at 160% full load. The temperature of the bus conductors shall not exceed maximum limit of 105˚C under these loading conditions. The bus duct assembly shall be compatible in design and construction with the rectifier, DC switchgear and the negative equalizer bus and drainage board, and shall operate as an integral unit when assembled.

3. Enclosure of bus duct assembly shall be ventilated, fabricated from high strength, corrosion resistant aluminum. Bus enclosure and supports of positive bus shall be insulated from building structure for 1,000 volts.

4. The enclosure of the negative cathode bus duct shall be properly isolated and insulated from the rectifier frame as described in Article 2.07.C above.

5. Suitable support of bus enclosures shall be provided as required to ensure rigid structure and workmanlike installation of the system.

6. For connection of future harmonic suppression filters, each cathode bus duct assembly shall be provided with bus taps, rated not less than 1/3 of the continuous current rating of the main bus. The exact location where the tap will be provided in each bus duct shall be furnished by the Contractor for approval of the Engineer. Taps provided shall enable connection of future bus ducts with minimum of labor and without involving drilling of main bus bars.

7. Flexible terminations shall be provided at each end of positive and negative cathode buses for connecting the bus conductors to equipment. Positive bus termination details shall be fully coordinated with the rectifier specified in Article 2.05 and the DC switchgear specified in Article 2.06, this Section. Connection details of negative bus shall be fully coordinated with the negative equalizer bus and drainage board specified in Article 2.08, this Section, and the rectifier.

8. Enclosure of the positive cathode bus bonded to rectifier enclosure shall be insulated from DC switchgear structure by installation of boxed micarta or fiberglass section in the vertical portion of the bus duct, at the DC switchgear, providing a minimum of six inch clearance between the metal enclosure of bus duct and nearest metal on DC switchgear. As an alternative, an insulated section in horizontal bus run at the DC switchgear, providing a minimum of two

feet clearance between the metal bus enclosure and the nearest metal part connected to the DC switchgear enclosure, is acceptable. A similar vertical or horizontal insulated section shall be provided in the enclosure of the negative cathode bus near the rectifier, to insulate it from the rectifier enclosure.

0.8 NEGATIVE EQUALIZER BUS AND DRAINAGE BOARD

A. General

1. A negative equalizer bus and drainage board shall be provided, located as shown on Contract Plans. Negative leads of the rectifiers shall be connected to the negative equalizer bus through a negative lead disconnect switch which shall be part of the negative drainage board.

2. The two bonding cables from AC switchgear insulated ground bus shall be connected to the negative equalizer bus through a blocking diode and one drainage contactor. One diode, rated 250 amperes, 400 volts, shall be provided for each of the two bonding cables. All other drainage cables will be provided by others.

B. Structure

1. The negative drainage board shall consist of a freestanding panel, containing the negative equalizer bus, rectifier negative lead disconnect switches, Device 89N, negative drainage contactors, blocking diodes, shunts and connectors for negative return cables.

2. Panel frame shall be fabricated from steel members of sufficient strength to provide rigid support for the negative equalizer bus and all devices. One inch thick, minimum, insulating board shall be provided on the front for mounting the negative disconnect switches and the drainage contactors. Front face below the insulating board and sides of the structure shall be enclosed with sheet steel plates. Rear shall be left uncovered to facilitate the installation of negative return cables.

3. Insulating board shall have high mechanical and dielectric strength, be impervious to moisture, be non-tracking and be able to withstand high temperatures without disintegration. The front surface shall be smooth and true. Edges shall be beveled for 1/4 inch. Material for the insulating board will be subject to approval by the Engineer.

4. The panel shall be amply sized to accommodate incoming negative bus ducts, outgoing negative return cables, control cables and outgoing drainage feeder cables. The negative buses are entering from the top, the negative return cables and drainage cables from the bottom as shown on Contract Plans.

5. All metal surfaces shall be finished in accordance with Article 1.16,

Section 16203. One quart of matching touch-up paint shall be shipped with the board.

C. Negative Equalizer Bus and Power Terminations

1. Negative equalizer bus shall run the full length of the panel. The negative equalizer bus shall have the same continuous current rating as the DC switchgear main bus in the Substation. Bus shall be supported on insulators with bus clamps mounted on the back of the panel. Taps shall be provided for connecting to negative disconnect switches. Negative equalizer bus and all bus taps shall be of copper, provided in accordance with Article 1.06, Section 16203. All bus taps and connections shall be tightly bolted. Contact surfaces of bolted joints shall be factory silver plated.

2. Heavy duty bolted type terminal lugs having four-bolt cable clamp and four-bolt tongue with NEMA standard drillings, shall be provided in accordance with Article 1.07, Section 16203 for 8-2,000 kcmil negative return cables. Terminal lugs shall be arranged for disconnecting any cable without disturbing the remaining cables. Back-to-back mounting of terminal lugs are not acceptable. Individual supports for each cable shall be provided near the terminal.

3. Drainage contactors mounted on the panel shall be connected to the equalizer bus. Provisions shall be made for connections to two additional contactors in the future.

D. Negative Lead Disconnect Switch

1. Negative lead disconnect switch shall be single pole, open type, rated for operation on 750 volts DC. The switch shall have the continuous current rating of 8,000 amperes. Switch shall be mounted in the rear of the panel. One switch terminal shall be directly connected to the negative equalizer bus, the second shall be arranged for connection to the negative cathode bus from the rectifier. All connections shall be made with a minimum of four 1/2 inch-13 bolts. Switch shall be operable by an insulated handle from the front of the drainage board.

2. Switch shall be equipped with a mechanical lock or catch to hold it firmly in either open or closed position. Nameplates shall be provided to indicate the open and closed position of switch. Nameplate shall also be provided to indicate the rectifier number to which negative cathode leads the switch is connected to.

3. Switch shall be provided with a key interlock, as described in Article 1.14, Section 16203, to prevent closing or opening of the switch unless the rectifier main DC circuit breaker is open. An auxiliary switch shall also be provided, having four independent contacts with two open when the switch is closed and two closed when the switch is open, for remote rip and alarm. Switch shall be of the bolted

pressure contact type with a proven record and verifiable references on similar application.

E. Drainage Contactors, Surge Arrester, Blocking Diodes and Associated Equipment

1. The drainage contactors shall be of the latched-in type, open, rear connected, single pole, rated 600 volt DC, 600 ampere, having high contact pressure and rapid arc quenching properties. Operating and reset coils shall be rated for operation on 125 volt DC. Six contactors shall be provided.

2. Contactors shall be mounted on front of the panel and shall be factory wired to the negative equalizer bus. Contactors shall be provided with a four-digit register type operations counter.

3. All contactors shall be electrically interlocked with rectifier main DC breakers so that all the contactors will be in closed position as long as any one or both of the main DC breakers are closed, and all the contactors will be open when both the rectifier main DC breakers are open. All circuits requiring external connection shall be factory wired to an easily accessible terminal box for connection to field wiring.

4. A blocking diode rated 600 amperes, 400 volts, and a shunt rated 600 amperes, 50 millivolts shall be provided, connected in series with each drainage contactor.

5. An isolation amplifier, as specified in Article 1.11, Section 16203, shall be provided for each drainage circuit, connected to shunt leads for telemetering drainage current.

6. An approved surge arrester, rated 750 volt DC, shall be provided, factory wired from negative equalizer bus to equipment ground terminal.

F. Nameplates

1. In addition to nameplates specified for equipment and devices in Article 1.08, Section 16203, the Contractor shall provide a nameplate, mounted above the operating handle of each switch, engraved "DO NOT OPEN UNDER LOAD". The nameplate shall have white letters, 1/2 inch high, minimum, on red background.

2. The legend of the nameplates shall be submitted to the Engineer for approval.

0.9 15 kV BREAKER CONTROL AND INSTRUMENT PANEL

A. The control and instrument panel is intended for remote control of 15 kV incoming and outgoing feeder and auxiliary feeder circuit breakers and for feeder alive indication.

B. Structure

1. The control and instrument panel shall be a rigid, self-supporting, electrically welded steel structure fabricated from not less than 12 gauge formed sheet steel. The panel shall have the configuration and dimensions shown on Contract Plans.

2. Hinged, full-access double doors shall be provided in the front. Doors shall be formed of sheet steel and shall be properly reinforced against distortions by suitable flanges and stiffening members. Hinges shall be heavy duty of type approved by the Engineer. Doors shall be of the overlapping design, furnished with a three-point latching mechanism and key-locking handle. Doors shall be provided with stops to hold them securely in open position.

3. Provisions shall be made to secure control cables as they enter from below and as they are installed within the cabinet before being terminated.

4. A full size panel shall be installed in the panel for mounting the terminal blocks.

5. The panel shall be finished inside and outside in accordance with Article 1.16, Section 16203.

C. Arrangement of Devices

1. Control and selector switches, Devices 1 and 43, and indicating instruments shall be arranged to form a part of the mimic bus as shown on Contract Plans.

2. The mimic bus shall show the configuration of the 15 kV buses and circuits as depicted on Contract Plans.

3. The mimic bus shall be made of 3/8-inch wide and 1/8-inch thick solid colored red plastic bar, attached to the panel with epoxy adhesive.

D. Wiring and Terminal Blocks

1. All wiring shall be No. 12 AWG, stranded tinned copper, in accordance with Article 1.09, Section 16203.

2. Circuits requiring external connections shall be factory-wired to readily accessible terminal blocks rated 600 volts as specified in Article 1.09, Section 16203.

E. Meters, Switches, Indicating Lights

Indicating instruments, control and selector switches and indicating lights shall be provided in accordance with Article 1.10, Section 16203.

F. Special Requirements

1. The control panel shall be provided with electric space heaters of adequate size to prevent condensation within the panel. The heaters shall be monitored by means of an ammeter scaled and marked for the heater load. The heater circuit shall be provided with an indicating light with blue lens to indicate operation of the heater, and an ON-OFF switch. Heaters shall be provided with properly designed guards to protect operating personnel against accidental contact with hot surfaces. Heaters are to be located so that they will not interfere with or damage the control and instrument cables.

2. The space heaters shall be rated for operation on 120 volt, 60 Hz supply.

G. Nameplates

1. Nameplates shall be provided in accordance with Article 1.08, Section 16203.

2. Panel identification nameplates shall be provided in front and rear of the panel, engraved "15 kV BREAKER CONTROL AND INSTRUMENT PANEL".

H. Detailed Equipment Requirements

The control and instrument panel shall contain, but not be limited to, the following equipment and devices.

1 - Panel enclosure, as specified
11 - Control switches, TRIP-CLOSE with green and red indicating lights, Device 1
11 - Breaker control mode selector switches LOCAL-OFF-SUPV, Device 43.
2 - Dummy control switch escutcheons with red and green indicating lights
12 - Indicating voltmeters, transformer rated, 0-18 kV scale
1 - Lot of mimic buses
1 - Set of space heaters with ON-OFF switch, blue indicating light and ammeter
1 - Lot of terminal blocks and wiring
1 - Lot of nameplates

0.10 STATION BATTERY, CHARGER AND ACCESSORIES

A. General

1. Station battery will serve as the primary source of ungrounded 125 volts DC control power for AC and DC circuit breakers, rectifiers, and station auxiliary systems located in the Substation.

2. One complete station battery system shall be furnished, including station battery, rack, charger, spill containment system, distribution

panel and accessories. The station battery shall be connected to the main circuit breaker of the 125 volts DC distribution panel (negative lead directly, positive lead through external shunt) and the charger to the DC distribution panel through a branch circuit breaker. Thus connected, the equipment can be used to supply the 125 volt DC control power system from the station battery and the charger operating in parallel, or from the station battery alone, or from the charger alone.

3. All equipment shall be suitable for indoor installation as shown on Contract Plans.

B. Station Battery

1. Station battery shall be of an approved pasted plate type, designed for switchgear service. Battery, as applied, shall give a minimum of 20 years of satisfactory service with a minimum amount of maintenance.

2. Each battery shall consist of 60 cells connected in series for a nominal 125 volt, ungrounded, control power system. Each cell shall be housed in a heat resistant, shock absorbing clear plastic container of extra strength which will not deteriorate or become cloudy upon exposure to the electrolyte. Covers shall be cemented in place to form a permanent, leakproof seal. Each cell shall be provided with a filler opening fitted with a safety cap to prevent and explosion of internal cell gases due to an external spark or flame. Sufficient sediment space shall be provided for the normal life of the battery. Each cell shall be legibly and permanently marked with the manufacturer's name or trademark, cell type, eight hour discharge rate, ampere-hour capacity, electrolyte level and month and year of manufacture.

3. Cell terminal posts shall be of lead-alloy, clearly and permanently marked for polarity. Cell posts shall be equipped with approved lead covered or stainless steel terminal bolts and nuts. Lead covered copper intercell connection straps shall be provided as required for interconnection of the individual cells. Interconnections shall be arranged to allow the removal of each cell from the battery. Battery terminals shall be furnished with approved lead covered, bolted type terminal lugs for external wiring. Cell posts, connection bolts, straps and terminal lugs shall have ample current carrying capacity and sufficient contact surface to provide for maximum discharge current of the battery.

4. The terminals through the cell cover shall be sealed against seepage of electrolyte by burned-on seal rings, to ensure a clean, dry battery.

5. It shall be the responsibility of the Contractor to size the battery for the Substation. Ratings of battery will be subject to Engineer's approval. Battery sizing shall be based on the following:

a. The batteries shall be of required ampere-hour capacity to supply the high discharge rates necessary to close and trip the specified number of 15 kV AC circuit breakers and 750 volt DC circuit breakers consecutively after the battery has supplied, without assistance from a charging source, the lower rate continuous load for 12 hours. The battery shall be sized for the following load cycle:

Ampere	Assumed Load Duration	Interval of Load Application	
Authority's Load	3.0A	12 hours	
Annunciator (assume 30 points activated	*	12 hours	
Control circuit load	*	12 hours	
Closing 4-15 kV breakers	*	30 sec.	30 sec. apart consecutively
Closing 4-DC breakers	*	30 sec.	30 sec. apart consecutively
Tripping 7-15 kV breakers by Device 86B	*	30 sec.	Simultaneously
Tripping 4-DC breakers	*	30 sec.	Simultaneously

* - Load to be determined by the Contractor

b. The voltage of the battery, when supplying the specified loads, shall at no time drop below 105 volts or 1.75 volts per cell, including the IR drop of inter-cell connections at the battery temperature of zero degrees C and specific gravity of electrolyte at 1.21.

6. Battery shall be delivered wet, fully charged, ready for service, suitable for storage at site for at least three months from shipping date without deterioration, or may be delivered dry with electrolyte shipped separately.

7. The battery shall be lead-acid type, with pasted plates and lead-calcium grid, Exide type EC, or approved equal. Gold and C&D batteries meeting all specification requirements will be acceptable.

8. Battery shall be furnished with accessories for normal operation and maintenance, including the following:

a. Two portable thermometers of adequate size to be read easily and accurately.

b. Two syringe type portable hydrometers of adequate size to be read easily and accurately.
c. A cell lifter.
d. An electrolyte filler or funnel.
e. A complete set of electrolyte resistant wrenches. If installation requires that connection bolts shall be tightened to a specific torque, a torque wrench shall be supplied.
f. A container of protective coating for battery terminals as recommended by the manufacturer.
g. An approved wooden or metal cabinet suitable for wall mounting to house accessories. Drip-proof containers shall be provided for the portable thermometers and hydrometers.

9. Contractor shall furnish the Engineer with the following information for the battery furnished:

a. Manufacture and type of battery
b. Ratings (to final voltage of 1.75 volts per cell, at 25˚C):
Amp hour rating for 8 hour discharge
Ampere rating for 1 hour discharge
Ampere rating for 1 minute discharge
c. Number of plates per cell
d. Dimensions of plates, including thickness
e. Weight of plates
f. A complete description of separators and plate separation
g. Method of assembly
h. Outside dimensions of jar
i. Weight of complete cell with electrolyte
j. Type of connectors
k. Quantity of electrolyte per cell
l. Specific gravity of electrolyte when battery is fully charge at 25˚C
m. Description of bottom of jars, giving location of feet if feet are used
n. Overall dimensions of the cell
o. Method of sealing
p. Method of supporting plates
q. Material used for covers and jars
r. Description of cell posts and terminals
s. Station battery loads used in sizing batteries

C. Combination Power Supply and Battery Charger

1. The combination power supply and battery charger furnished will be used for supplying nominal 125 volt DC to control and relay circuitry and for float charging the station battery. It shall be rated for operation on 208 volt, three-phase, 60 Hz supply.

2. The charger shall be convection cooled, full wave rectifier type. The rectifier shall consist of hermetically sealed silicon diode units of silicon controlled rectifiers of adequate voltage and current rating for

this service. The diodes shall be mounted on heat dissipating fins of proper size to limit the junction temperature of the diodes to a safe value.

3. The power supply shall consist of a three-phase transformer and a rectifier with an adjustable regulated voltage and current limiting feature. Regulation shall vary less than plus or minus one percent at any control setting. It shall be adjustable between 127 and 140 volts DC and shall be capable of sharing the load with the battery when the load current exceeds a preset value. The preset current setpoint value shall be adjustable between 90% and 120% of the power supply continuous rating.

4. To function as a battery charger, the power supply shall have two separate voltage adjustments: one for float charge, adjustable between 122 and 138 volts; the second for equalizing charge, adjustable between 128 and 144 volts. An adjustable timer shall be provided, as specified, to control the charging and equalizing cycle.

5. The charger shall be provided with current limiting circuitry to keep the output of the charger within the safe operating limit under all loading conditions and during severe overloads. The circuit shall continuously monitor the load current and when the current begins to exceed charger rating (as may be the case of recharging depleted battery while supplying other DC loads in the Substation), a feed-back feature provided as part of the circuit shall keep the output current within 110% of rated. The charger shall be designed to operate continuously at this rating without damage to any circuit components. The current-limiting mode of operation shall not cause the tripping of input (AC) or output (DC) circuit breakers. The input circuit breaker shall trip only in case of component failure and shunt-trip for high DC output voltage; the output circuit breaker shall trip in case of an external fault.

6. A blocking diode shall be provided in the output circuit, to prevent battery discharge through the charger in the event of AC power failure.

7. The power supply shall be capable of concurrently carrying the constant load of the associated battery and fully charging the battery within six hours after is has been discharged to 1.75 volts per cell, and shall be able to carry the entire battery load in the event of a battery failure. The power supply shall be capable of operating safely at building ambient temperatures from minus 18˚C to plus 40˚C.

8. The current and voltage regulation of the power supply shall be accomplished by silicon controlled rectifier (SCR) conduction and blocking the AC input by phase shifting the SCR gate trigger pulses or by the automatic change of a series impedance which may be inserted at any point between the AC input and the DC output to the battery. The SCR conduction blocking period or the series impedance

shall vary in such a manner as to maintain a charging voltage proportionate to a manually adjustable reference voltage set from the front panel of the equipment enclosure.

9. The battery charger shall have a “filtered battery eliminator” feature that allows feeding the 120 volt circuit directly (without batteries connected) with an output that is filtered to minimize ripples at one percent of nominal output voltage. SCR regulation of the AC input will be permitted, provided the input phases conduct sequentially in such manner as to prevent all three input phases from being switched off simultaneously; provided the SCR's are back-biased to assure proper turn-off at elevated temperatures; and provided the SCR's and their controlling circuitry are transient protected so as not to change state due to shock excitation transients produced by the rectifier and so as not to change state with the operation of the substation circuit breakers when there is no battery connected on the output. Since the associated battery is not considered to be part of the output filtering network, electrolytic capacitors may be used to smooth-out the high magnitude output ripple voltage, provided such capacitors have protective circuitry and are 50% in excess of the capacitance value required for one percent ripple and are rated for operation at 100˚C. In such case, three capacitors shall be used, of such value that two will limit the ripple to one percent. The third capacitor is to be considered as a space which must be kept energized to prevent deterioration.

10. All solid state electronic circuit components shall be provided with surge and transient voltage protection.

11. The power supply circuit components and control devices shall be mounted in a free-standing, floor mounting cabinet, fabricated from not less that 12 gauge sheet steel. The equipment shall be mounted on a panel of insulating material, supported on a swinging steel frame. The frame shall form a component part of a self-supporting steel cubicle. Heavy components such as reactors, transformers and other iron core devices shall be supported by bracing to the swinging steel frame. A swing-out panel may be omitted in the power supply and battery charger unit only if all components are accessible from the front for easy maintenance, removal and inspection and the arrangement meets Engineer's approval.

12. Each resistor, capacitor, transformer and similar device shall be inscribed with an approved lettered identification corresponding to the apparatus or device with which it functions and as identified on the schematic and wiring diagrams.

13. The cabinet shall have hinged full-access front door. Door shall be securely fastened in the closed position with a minimum of two latches easily opened without the use of tools. Arrangements shall be made to hold door securely in the open position.

14. Control wiring of circuits operated on 60 volts AC or DC, or higher, shall be No. 14 AWG or larger, stranded tinned copper switchboard wire in accordance with Article 1.09, Section 16203. No. 18 AWG wire will be acceptable for low-voltage, low-energy control circuits only.

15. Circuits requiring external connections shall be factory-wired to terminal blocks, readily accessible for connection to field wiring.

16. Finish of equipment shall be in accordance with, Article 1.16, Section 16203, except inside surfaces shall be finished with two coats of semi gloss white enamel paint.

17. The equipment for the power supply and battery charger shall include, but not be limited to, the following:

    1 - Three phase power transformer with 208/120 volt primary.
    1 - Charger rectifier unit and associated control equipment.
    1 - Long-scale zero centered DC switchboard type ammeter, with suitable scale and an external shunt, for battery charge/discharge indication.
    1 - Long-scale DC switchboard type ammeter, with suitable scale and a shunt, for charger output current.
    1 - Large scale DC switchboard type voltmeter, 0-150 volt scale, for charger output voltage.
    1 - 250-volt, 3-pole alternating current shunt-tripped molded case circuit breaker.
    1 - 250-volt, 2-pole direct current molded case circuit breaker.
    1 - AC input circuit undervoltage relay, Device 27BA, with contacts for an indicating light and an external alarm.
    1 - DC output circuit overvoltage relay, Device 59, with contacts for an indicating light and an external alarm.
    1 - DC output circuit undervoltage relay, Device 27BB, with contacts for an indicating light and an external alarm.
    1 - Set of three indicating lights for Devices 27BA, 27BB, and 59, connected to an external 125 volt DC supply.
    1 - Large-scale 48-hour or 72-hour approved timer with sufficient contacts to switch the regulatory section of the power supply between float charge and equalization charge settings.
    1 - Set of ground detector relay with contact for remote alarm and ground detection light.
    1 - Set of ground detector resistors.
    1 - Second set of dry form “C” contacts (SPDT) without indicating lights for use in SCADA monitoring of the battery charger performance.

18. In addition to nameplates specified in, Article 1.08, Section 16203, furnish a nameplate on the door of the cabinet engraved: "125 VOLTS DC POWER SUPPLY". Nameplate shall have white letter, 1/2 inch high on red background.

D. Battery Rack

1. Contractor shall provide two two-step racks for mounting the individual cells of the station battery.

2. Battery racks shall be constructed of steel rails, frames and braces, bolted together to form rigid, free-standing structures. Racks shall be furnished with plastic channels for mounting the battery cells and must comply with the latest seismic requirements of the State Building Code. Contractor shall provide for each battery rack, two bolted type lead covered copper terminal lugs for No. 4/0 AWG stranded copper ground cable.

3. All steel members shall be thoroughly cleaned and rustproofed, painted with one coat of approved rust inhibiting primer and a minimum of two coats of acid resistant light gray paint.

E. Spill Containment System

1. Station battery installation shall be provided with a spill containment and absorption system. The materials used, method of application, and completed installation must fully meet all requirements specified in Article 64 of the 1994 Uniform Fire Code.

2. The electrolyte spill containment system shall consist of the following:

   a. A minimum of four-inch high barrier surrounding the two battery racks. The barrier shall be fabricated of non-corrosive materials, anchored to the floor and sealed to prevent free flow of the electrolyte.
   b. A layer of absorbing and neutralizing pads installed with the barriers. The pads must be capable of absorbing at least 65% of its volume of 1.25 specific gravity electrolyte and neutralize not less than 55% of the volume absorbed. Total amount of electrolyte to be absorbed shall be determined by the Contractor based on the volume of electrolyte in cells supplied.
   c. Details of the spill containment system shall be forwarded to the Engineer for approval.

F. DC Distribution Panelboard

1. A circuit breaker panelboard shall be provided with the substation battery system for distributing the 125-volt DC control power. Panelboard and all circuit breakers shall be of the Underwriters' Laboratory (UL) approved type, rated for operation on ungrounded 125 volt DC.

2. Panelboard interiors shall consist of a steel backplate structure holding the bus and terminal assemblies. The backplate shall be removable and shall be adjustable in depth unless the assembly for

the panelboard is specifically designed to ensure proper depth positioning of the panel interior without adjustment. Breakers shall be bolt-on type, factory installed. All spaces shall be fully bussed and equipped requiring no modification for the addition of future breakers. Unused space shall be covered to preclude accidental access to the bus.

3. Buses shall be of copper, silver plated, braced to withstand a short circuit equal to the highest short circuit capacity of any breaker installed in the panel.

4. Circuit breakers shall be molded case, two pole, with trip free mechanism. Trip elements shall be thermal and magnetic type.

5. Circuit breakers shall have a minimum interrupting rating of 10,000 amperes at 125 volts DC. The buses and main circuit breaker in the panelboard shall have a continuous current rating of approximately 125% of the one minute rating of the battery. Provide branch circuit breakers in the panelboard of the quantities and ratings as follows:

   3 - 125 ampere, 2 pole
   2 - 100 ampere, 2 pole
   2 - 50 ampere, 2 pole
   1 - 30 ampere, 2 pole
   4 - 20 ampere, 2 pole
   2 - 15 ampere, 2 pole

6. Panelboard shall be factory assembled, furnished with NEMA type 1 general purpose surface mounting cabinet. Cabinet shall be of a gauge not less than that specified by the applicable UL standard. Wiring gutters shall conform with the requirements of the National Electrical Code and the applicable UL standards, but in no case shall be less than four inches. Box shall be furnished with single size knockouts or may be field drilled. Spare knockouts or combination knockouts shall not be furnished.

7. Panelboard front shall be of a gauge not less than that specified by the applicable UL standard and shall be of cold rolled or other suitable steel with concealed hinges, concealed trim clamps and flush catch and lock. Lock shall be keyed as approved by the Engineer. A typewritten directory with plastic covering shall be installed on the interior of the door.

8. Cabinet shall be hot-dipped galvanized after fabrication. Front shall be thoroughly cleaned and finished with a rust inhibiting primer. Panelboard shall be finished in accordance with Article 1.16, Section 16203.

9. In addition to nameplates specified in Article 1.08, Section 16203, Contractor shall provide a nameplate on the door of the panelboard engraved "125 VOLT DC DISTRIBUTION PANEL". Nameplate shall

have white letters, 1/2 inch high on red background.

0.11 SUPERVISORY EQUIPMENT

A. General

The requirements for additions and modifications to Authority's existing SCADA system and for furnishing a separate, new one-on-one supervisory system for the _____ Traction Power Substation are detailed and specified in Article 2.02.C, Paragraphs 5 and 6, this Section.

B. Interface Terminal Box

1. The interface terminal box shall be a NEMA12 enclosure, fabricated from not less than 12 gauge sheet steel. It shall be provided with a factory- installed floor stand, to make the terminal box a freestanding, floor-mounting cabinet.

2. Hinged, full access double doors shall be provided in front. Doors shall be of overlapping design, furnished with neoprene gaskets and a three-point latching mechanism with key-locking handle. Doors shall be provided with stops to hold them securely in open position.

3. A full size panel shall be installed in the enclosure for mounting the terminal blocks.

4. Terminal blocks furnished shall conform to the requirements specified in Article 1.09, Section 16203. A minimum of 25% spare terminals shall be provided for future application.

5. The terminal box shall be finished inside and out in accordance with Article 1.06, Section 16203.

6. Contractor shall provide a nameplate on the door in accordance with Article 1.08, Section 16203, engraved in 3/4" letters: "SUPERVISORY TERMINAL BOX".

0.12 DC CIRCUIT BREAKER TESTER

A. General

1. The DC circuit breaker tester shall be designed to provide accurate, variable, high DC current for testing and calibrating the direct-acting magnetic trip devices of the Authority's 750-volt DC traction power circuit breakers.

2. The tester is to replace the *obsolete* Hipotronics DC Tester Model No. 9003-25-DC presently in use at the Authority.

B. Basic Requirements

1. The direct acting magnetic trip devices are the major protective

elements of traction power feeders and circuit breakers. Consequently, they must be accurately set and calibrated to eliminate as far as practicable, nuisance tripping which may become a safety sensitive issue to the riding public.

2. The intent of this Specification is to provide an accurate power source to adequately test the traction power circuit breakers manufactured by ABB (I-T-E), CPC, GEC and Whipp and Bourne presently in use at the Authority, the DC circuit breakers to be furnished under this Section and other DC circuit breakers on the market today. It is imperative that the output of the tester throughout the specified current range is stable, sufficiently free of harmonics and will not produce appreciable errors in testing these circuit breakers.

3. The DC tester shall be SCR controlled, solid state, mobile high current test set designed specifically for testing 600-volt DC circuit breakers. The test set will incorporate a variable high current output, control circuitry instrumentation, overload and short circuit protection.

C. Technical Data

1. Ratings

   a. Input Voltage: 480, 3-Phase, 60Hz
   b. Input Current: not to exceed 45 amperes continuous, 270 amperes instantaneous
   c. Output Current:

Duration	Current
15 minutes	5,000A
40 seconds	12,000A
15 seconds	22,500A
3 seconds	30,500A

2. Digital Timer

   a. Tester shall be equipped with a timer to measure the elapsed time to test in either seconds or cycles
   b. Timer should start at the beginning of each test and automatically stop when the device under test operates.
   c. Timer should be equipped with circuitry to start and stop the timer and de-energize the output of the test set. The input to the start and stop timer shall accept normally open contacts, normally closed contacts or accommodate a device that has no auxiliary contacts and shall sense current to start/stop the timer.
   d. Timing Requirements

Ranges	% Error
0-999.999 seconds	.0025%
0-9999.9 cycles	+/- 0.5 cycles

3. Dimensions and Weight: Unit may be modular to facilitate transporting to remote locations. Dimensions should not be larger or weigh more than the existing test set.

4. Existing DC Tester Nameplate Data

Mfg.	Hipotronics
Model No.	9003-25KA-DC
Serial No.	DS19-1075
Mfg. Ref No.	76-24699
Dimensions	L 61□,W 32□, H 72□
Weight	3000 Lbs

5. Overload Protection: The circuit test set is to be provided with a circuit breaker, overload relays, and fuses to protect it from extreme or prolong overloads. The test set shall be equipped with a temperature sensitive interlock switch which will de-energize the test unit in event of abnormal heating.

6. Output Connections: Output connections must permit direct engagement of drawout type circuit breakers on wheels. The Contractor shall provide adapter bus plates that will allow testing of each type of DC breaker presently in operation at the Authority and to permit direct connection of a drawout type circuit breaker to the tester. This will require the Contractor to visit a number of MBTA Traction Power Substations to measure all bus stabs for the different types of DC breakers in the system. The tester shall also be capable to test the new breakers purchased under this Section.

7. Portability: The tester must be portable, include lift hooks, any special straps, and proper moving instruction. For ease of transportation the test set shall be housed in a durable metal enclosure equipped with casters and handles.

8. Ammeter: An electronic memory type indicating ammeter shall be provided to measure the output current of the tester, having an overall full scale accuracy of □2%, assuming balanced three-phase input to the test set. Ammeter shall have following full scale ranges: 0-250/500/1,000/2,500/5,000/10,000/25,000/50,000 amperes DC.

9. Recording Ammeter

Tester shall be equipped with a recording DC ammeter capable of recording the maximum DC output current during the minimum time cycle and all other current/time combinations within the range of the tester. Recording ammeter overall system accuracy shall be within ±5% of true value of the current measured.

The recording ammeter shall be single channel, fast response type. Response shall be 0.4 seconds or less, if a 100 MV shunt is supplied, or 0.3 seconds, if a 200 MV or 300 MV is supplied. Recorder shall have a 10-inch wide recording chart. Acceptable models are Esterline-Angus Speed Servo Model L11015-C, or Hewlett Packard Model 7101 B/BR, or approved equal. Twenty-four recording charts shall be supplied with the recorder.

0.13 TECHNICAL SUPPORT EQUIPMENT

A. General

The Contractor shall ensure that adequate supply of equipment, parts, materials, tools and required equipment for protection of operating personnel are available at the site for orderly installation and testing of equipment without undue delay. These do not constitute requirements of spare parts for normal operation but only the requirement to cover the period during installation, testing and commissioning.

B. Requirements

1. Contractor shall furnish the following tools, parts, hardware, etc. delivered with the shipment of related equipment for which they are required:

    a. Three vacuum interrupter bottles.
    b. One additional 13,800 volt AC and 1000 volt DC current limiting fuse for each such fuse installed in the equipment.
    c. Ten percent of all control and auxiliary circuit fuses and two percent of all fuse blocks but not less than two fuses and one fuse block of each rating, installed in the equipment.
    d. For each type and rating of power circuit breaker, one of each type of electromotive device integral to the breaker, used for closing and tripping, including but not be limited to, closing coils, spring charging motors, trip coils or holding coils.
    e. One of each type of spring used in each type of circuit breaker.
    f. For each type of AC and DC power circuit breaker, one set of primary power current carrying disconnect assemblies, two complete sets of secondary control disconnect assemblies and one set of auxiliary switches.
    g. Twelve diodes, for power rectifier.
    h. Twelve diode fuses.
    i. One surge arrester assembly of each type.
    j. Two bimetallic thermal devices for each rating for rectifier heat sink over-temperature detection.
    k. One protective relay of each type, complete with case.

l. One empty case for each type of protective relay.
m. Five annunciator plug-in sequence module units.
n. Two control, auxiliary, and timing relays of each type furnished with the equipment.
o. One lot of recording paper, as approved by the Engineer, ink and other supplies for operating the recording voltmeter and wattmeter for a minimum of 360 days.
p. One plug-in electronic control card of each type, for the battery charger.
q. One complete set of tools, in a tool cabinet, required for installation, adjustment, testing, maintenance and dismantling of all the equipment to be furnished in this Section. Tools shall specifically contain those required for major equipment such as AC and DC metal clad switchgear, high and low voltage circuit breakers, rectifier transformers, rectifiers and auxiliaries, station battery, bus ducts, etc.
r. Two platform stools, step type, with wheels that lock when weight is applied, as approved by the Engineer.
s. One set of the following substation operator's safety equipment:
- Switchman's coat, 100% 11.5 ounce Proban cotton, extra large, Industrial Protection Products Model No. 3E-400-54KB, or similar as approved by the Engineer.
- Switchman's hardhat with hood, Industrial Protection Products Model No. UV-7AF-3A-1 or similar as approved by the Engineer.
- Rubber gloves, 16-inch, Salisbury Rubber Cat. No. 20-16B, or similar as approved by the Engineer.
- Leather hand protector, 6-inch cuff, size No. 12, Salisbury Rubber Cat. No. 156-6, or similar as approved by the Engineer.

PART 3 - EXECUTION

0.1 GENERAL

A. Contractor shall install all equipment specified in this Section in accordance with requirements of this Specification at the locations shown on the Contract Plans, with Engineer approved changes, if any. Installation of 15 kV power cables, including the required conduits, supports and fittings, shall be in accordance with Section 16120. DC traction feeder positive and negative return cables and DC traction power disconnect switches shall be installed in accordance with Section 16125. Low voltage power and control wiring installation including installation of required conduit and fittings, cable trays, junction, pull and terminal boxes and related materials shall be in accordance with Section 16050. The completed installation shall provide fully coordinated and fully operational electrical system.

B. The Contractor shall take every precaution in handling, setting, aligning and assembling the equipment to avoid distortion of frames. The Contractor shall thoroughly familiarize himself with the manufacturer's instructions before attempting to handle, install and operate the equipment. Contractor shall ensure that all personnel working with the

equipment fully understands the operation of the various components to avoid misoperation, damage to equipment and possible personnel injury.

C. All equipment assembly connections to mechanically assemble the units shall be made, including all bolted connections between shipping units, between equipment and bus duct enclosures and anchoring the equipment to the floor.

D. All electrical connections between shipping units, including all bolted bus connections and connections of control and auxiliary circuits shall be made.

E. Contractor shall furnish, install and connect all 13.8 kV AC circuit cables and DC traction feeder positive and negative cables shown on Contract Plans. Routing and method of installation of 13.8 kV AC circuit cable, associated conduits and DC traction feeder cables are shown on Contract Plans.

F. Conduits and cables for control and auxiliary circuits for interconnecting equipment and devices are not shown on Contract Plans. Contractor shall determine the application of these cables to satisfy all control, indication, supervisory and auxiliary functions specified. Installation of cables shall be in accordance with Contractor's prepared and Engineer's approved cable schedules and installation drawings.

G. The Contractor shall make all ground connections to the equipment from the ground buses in the Substation as shown on the Contract Plans.

H. All electrical connections between shipping units, including all bolted bus connections and connections of control and auxiliary circuits shall be made.

I. Contractor shall furnish install and connect all 13.8 kV AC circuit cables and DC traction feeder positive and negative cables shown on Contract Plans. Routing and method of installation of 13.8 kV AC circuit cable, associated conduits and DC traction feeder cables are shown on Contract Plans.

J. Conduits and cables for control and auxiliary circuits for interconnecting equipment and devices are not shown on Contract Plans. Contractor shall determine the application of these cables to satisfy all control, indication, supervisory and auxiliary functions specified. Installation of cables shall be in accordance with Contractor's prepared and Engineer's approved cable schedules and installation drawings.

K. The Contractor shall make all ground connections to the equipment from the ground buses in the Substation as shown on the Contract Plans.

L. All structural steel members used for support of electrical equipment and materials shall be furnished in accordance with Section 09900 and 09110.

M. Complete installation shall be tested and checked out in accordance with Article 3.03, this Section and as specified in other applicable Sections of this Specification.

0.2 INSTALLATION

A. 15 kV AC Switchgear

1. The 15 kV AC switchgear shall be fully assembled and completely installed in accordance with manufacturer's instructions at the location shown on Contract Plans.

2. Switchgear base channels, furnished with the switchgear, shall be installed in the floor slab by the Contractor. The switchgear units shall be anchored to the base channels with sufficient number of bolts to withstand impact resulting from breaker operation and to satisfy the seismic requirements specified in Article 2.01, this Section. All bolts required for anchoring the switchgear shall be furnished by the Contractor.

3. Switchgear units shall be assembled in such a manner as to ensure proper leveling, proper alignment between the various shipping groups and for proper placement of all primary circuit conduits that are required for equipment interconnection.

4. Breaker test cabinet shall be installed at the location shown on Contract Plans. A clear space of 1/4 inch, minimum, shall be provided between the back of the cabinet and the wall. Steel channels or straps, or equal of suitable thickness shall be fastened to the masonry and be drilled and tapped for mounting the test cabinet using galvanized bolts. Contractor shall furnish, install and connect the 125-volt DC control supply wiring from the DC distribution panel.

5. After completion of switchgear installation, the Contractor shall ensure that all doors and the drawout fuse and PT carriages operate freely and the breaker removable elements and the ground and test device can be moved into and removed from the housings without encountering the change of elevation from within the housing to the floor. Contractor shall correct all misalignments to the satisfaction of the Engineer.

B. Rectifier Transformers

1. Rectifier transformers shall be fully assembled and completely installed in accordance with manufacturer's instructions at location shown on Contract Plans.

2. Low voltage terminals of the transformers shall be connected to the non- segregated phase bus duct as specified in Article 2.07, this Section.

C. Rectifiers and Accessories

1. Rectifier units shall be fully assembled and completely installed in accordance with Engineer's approved manufacturer's drawings at locations shown on Contract Plans.

2. Insulated anchors, furnished with the rectifiers, shall be installed in the floor slab by the Contractor in accordance with manufacturer's instructions. The floor area at the rectifier units will be covered with a layer of insulating material by the Contractor, to insulate the rectifier enclosure from the building structure. Care shall be taken that the insulated floor area is not scraped or otherwise damaged during installation. All bolts required for anchoring the rectifier unit shall be furnished by the Contractor. After completion of the installation the rectifier enclosure shall be completely insulated from the building structure. The installation of rectifier shall satisfy seismic requirements specified in Article 2.01, this Section.

3. Rectifier units shall be connected to the rectifier transformer via the AC anode bus and to the rectifier DC main circuit breaker in the DC switchgear via the positive cathode bus as specified in Article 2.07, this Section. Rectifier negative terminal shall be connected to the equalizer bus and drainage board, specified in Article 2.08, this Section, via the negative cathode bus.

D. DC Switchgear

1. DC switchgear shall be fully assembled and completely installed in accordance with Engineer's approved manufacturer's drawings at location shown on Contract Plans.

2. Insulated anchors, furnished with the DC switchgear, shall be installed in the floor slab in accordance with manufacturer's instructions by the Contractor. The floor area at the DC switchgear shall be covered with a layer of insulated material by the Contractor, to insulate the switchgear enclosure from building structure. Care shall be taken that the insulated floor area is not scraped or otherwise damaged during installation. All bolts required for anchoring the switchgear shall be furnished by the Contractor. After completion of the installation, the DC switchgear structure shall be completely insulated from the building structure. The installation of switchgear shall satisfy seismic requirements specified in Article 2.01, this Section.

3. The switchgear units shall be assembled in such a manner as to ensure proper leveling, proper alignment between the various shipping groups and for proper placement of all the conduits that are required for equipment interconnection. The Contractor shall make all necessary electrical connections between the units of the assembly, including the joints in the 650 volt positive bus.

4. The rectifier DC main circuit breakers shall be connected to the rectifiers via the positive cathode bus as specified in Article 2.07, this Section.

5. The breaker test cabinet shall be installed at the location shown on Contract Plans or as directed by the Engineer. A clear space of 1/4 inch, minimum, shall be provided between the back of the cabinet and the wall. Steel channels or straps, or equal, of suitable thickness shall be fastened to the masonry and tapped and drilled for mounting of the test cabinet using galvanized machine bolts. The Contractor shall furnish, install and connect the 125-volt DC control supply wiring from the DC distribution panel.

6. After completion of the installation, the Contractor shall ensure that all doors operate freely and the breaker removable elements can be moved into and removed from the housings without encountering the change of elevation from within the housing to the floor. Contractor shall correct all misalignments to the satisfaction of the Engineer.

E. AC and DC Bus Ducts

1. The bus ducts interconnecting the DC switchgear, rectifier transformers, negative drainage board and rectifier equipment shall be fully assembled and completely installed in accordance with Engineer's approved manufacturer's plan and detail drawings as shown on Contract Plans.

2. Bus ducts shall be provided with suitable mounting hangers supported from the ceiling slab or structural members, or as directed by the Engineer. Contractor shall furnish and install all trapezes, brackets, rods, clamps, suspension fittings and miscellaneous steel to provide a complete, firm and rigid support system for the bus ducts under all operating conditions and during short circuits. Supports shall be designed and installed in a manner to minimize induced circulating currents and induced magnetic heating.

3. All ferrous elements of the support system shall be hot dipped galvanized in accordance with Section 09910. Hangers supporting rectifier positive cathode buses and ungrounded portions of anode and cathode negative buses shall be provided with approved insulators to insulate the bus enclosures from the building structure.

4. Bus ducts shall be assembled in such manner as to ensure proper alignment between the shipping sections and the equipment they connect. After alignment and leveling, the bus enclosure shall be bolted to the equipment and then the enclosure splice plates shall be attached and securely fastened.

5. Insulated bus enclosure sections shall be installed in the rectifier anode and cathode bus runs to isolate the rectifier enclosure from its transformer and the DC switchgear enclosure and the negative

equalizer bus and drainage board enclosure.

6. Before electrical connections are made, all contact surfaces shall be wiped clean (sandpaper or abrasive tools shall not be used) and covered with a thin coat of approved grease. Joints in bus conductors shall be made using splice plates on each side of the conductor. Connections to equipment terminals shall be made with flexible connectors as specified in Article 2.07, this Section. All joints shall be made with a minimum of four 1/2 inch by 13 high tensile strength silicon bronze bolts and nuts. All nuts shall be provided with approved locking devices. All bolts shall be tightened to the torque of 40 foot-pounds, or as directed by the Engineer, using an accurate torque wrench.

7. After completion, all joints shall be covered by die-molded, flame retardant polyvinyl chloride boots, or approved equal providing full voltage insulation for the joint. These boots shall be easily removable for inspection of the joint without destruction of the boot.

F. Negative Equalizer Bus and Drainage Board

1. The negative equalizer bus and drainage board (NEBDB) shall be completely installed in accordance with Engineer's approved manufacturer's drawings at location shown on Contract plans.

2. The NEBDB shall be fastened to the floor slab with sufficient number of machine bolts and expansion anchors to satisfy the seismic requirements specified in Article 2.01, this Section.

3. The negative bus duct enclosures shall be accurately aligned and leveled for proper attachment to NEBDB enclosure. All connecting bolts shall be securely fastened.

4. Connections between bus duct conductors and buses at NEBDB shall be made with flexible connectors as specified in Article 2.07, this Section. Before connections are made, all contact surfaces shall be wiped clean and covered with a thin coat of approved grease. All bolts shall be tightened to the torque of 40 foot-pounds, or as directed by the Engineer, using an accurate torque wrench.

5. The two bonding cables from the AC switchgear insulated ground bus shall be connected to the negative equalizer bus as specified in Article 2.08, this Section.

G. Station Battery, Charger and Accessories

1. Battery racks shall be assembled in accordance with manufacturer's instructions at location shown on Contract Plans. The individual rack members shall be firmly bolted together to form rigid structures. Battery cells shall be mounted on plastic rails and provided with restraining rails for earthquake protection.

2. Each cell on the racks shall be numbered with approved, clearly visible numerals. Numbering shall start from battery positive terminal.

3. The Contractor shall remove the battery cells from shipping containers and inspect each cell for damage. If electrolyte has been lost in transit and the level is higher than 1/2 inch below top of plates, the Contractor shall fill the cell with electrolyte of 1.21 specific gravity. Cells with electrolyte level lower than 1/2 inch below top of plates shall be replaced by the Contractor.

4. Cells shall be set on rack with plates at right angles to the rails. Cells shall be spaced on the rack so that the intercell connectors can be installed without stressing the cell posts. All current carrying surfaces shall be scraped bright and clean and covered with a thin film of approved grease. Bolts shall be tightened to proper tension and the surplus grease wiped off. After completion of all connections, the polarity of each cell shall be checked with a voltmeter.

5. The Contractor shall install a spill containment barrier around each battery rack, as specified in Article 2.10.E., this Section. The barrier shall be fastened to the floor with non-corrosive machine bolts and expansion anchors. The barriers shall extend a minimum of two inches in each direction beyond the rack and shall be sealed all around with approved caulking compound to prevent seepage. Absorbing and neutralizing pads shall be installed to cover the entire area encompassed by the barriers. The spill containment system shall be installed in accordance with Engineer's approved manufacturer's instructions, after completion of station battery installation.

6. The Contractor shall install the power supply-battery charger unit at location shown on Contract Plans or as directed by the Engineer. Unit shall be fastened to the floor using approved expansion anchors.

7. The DC distribution panel shall be installed at the locations shown on Contract Plans. A clear space of 1/4 inch, minimum, shall be provided between the back of the panel and the wall. Steel channels or strips, or equal, of suitable thickness shall be fastened to the masonry and drilled and tapped for mounting the panel using galvanized machine bolts.

8. An approved battery work shelf shall be furnished by the Contractor and installed near the battery as directed by the Engineer.

9. After the completed installation is tested and checked out in accordance with all applicable portions of Article 3.03, this Section, the battery shall be given a freshening charge to assure that all cells are fully charged. The charging cycle shall continue for approximately three hours after the specific gravity of the lowest gravity cell has not shown any increase. When the charging cycle is

completed, the Contractor shall read and record the specific gravity and voltage of each cell and temperature and electrolyte level of three cells. Contractor shall prepare a neatly typed tabulation of the readings, listing each cell individually, date it and forward five copies of the tabulation to the Engineer for record.

H. 15 kV Circuit Breaker Control and Instrument Panel

1. The 15 kV circuit breaker control and instrument panel shall be completely installed in accordance with Engineer's approved manufacturer's drawings at the location shown on Contract Plans.

2. The panel shall be fastened to the floor slab with sufficient number of machine bolts and expansion anchors to satisfy the seismic requirements specified in Article 2.01, this Section.

I. Supervisory Equipment

1. The SCADA and one-on-one supervisory system RTU's shall be completely installed in the Substation in accordance with Engineer's approved manufacturer's drawings at the location shown on Contract Plans. The one-on-one system MTU shall be installed at Authority's High Street Operation's Center as directed by the Engineer.

2. The RTU's and the MTU shall be fastened to the floor slab with sufficient number of machine bolts and expansion anchors to satisfy the seismic requirements specified in Article 2.01, this Section.

3. Three two-wire leased telephone circuits for communication and data transfer between the SCADA and one-on-one RTU's in the Substation and master terminal equipment at the High Street Operation's Center will be provided and installed by others. These lines will be terminated at Contractor's provided and Engineer's approved surge protection devices. The surge protection devices shall be located near the line entry. Extensions of these lines from the surge protectors to the RTU and MTU equipment shall be furnished, installed and connected by the Contractor.

4. A qualified technical representative from the equipment manufacturer shall be provided by the Contractor *for a minimum of five (5) working days* to assist in the proper installation and interfacing of the supervisory equipment at the Substation and at the High Street Operations' Center.

0.3 TESTS

A. General

1. All equipment to be furnished and installed shall be subject to the following test program. Testing shall include tests at a manufacturer's facility and in the field.

2. The Contractor shall formulate an overall test program for all equipment furnished under this Section, which shall include but not be limited to the tests specified in this Section to ensure equipment compliance with the relevant standards, this Specification and satisfactory and reliable performance in intended operation.

3. Tests at the factory shall include but not be limited to:

   a. Manufacturer's standard tests.
   b. Tests as listed in Article 3.03.C, this Section.
   c. Tests as per relevant NEMA, IEEE and ANSI Standards not included in Article 3.03.C.
   d. Any other tests to ensure satisfactory performance of equipment.

4. Tests in the field shall include but not be limited to:

   a. Tests as listed in Article 3.03.D, this Section.
   b. Tests as per relevant NEMA, IEEE and ANSI Standards not included in Article 3.03.D, this Section.
   c. Any other tests to ensure satisfactory performance of equipment.

5. The Contractor shall meet the requirements in Article 3.03.B, this Section, for testing and shall furnish test reports as specified in Article 3.03.E, of this Section for obtaining clearance for packing and shipment of equipment tested.

B. Conditions for Tests

1. General Conditions: Prior to testing of any equipment specified in this Section, all of the following conditions shall be fulfilled by the Contractor:

   a. Contractor has made the "For Record" submittal of shop drawings of the equipment scheduled for testing to the Engineer/Consulting Engineer. Please note that "For Record" submittal shall be made only after the previous submittal has been approved by the Engineer.
   b. The Contractor-prepared test procedure has been approved by the Engineer.
   c. Upon completion of "a" and "b" above, a minimum of four weeks advance notification shall be given to Engineer and Consulting Engineer on the scheduled date of tests to enable them to witness the tests.

2. Witnessing Tests: Engineer will witness complete testing of all equipment unless a waiver is granted, in which case test reports of equipment for which waiver was granted shall be submitted for review to obtain clearance for packing and shipping. Waiver of witnessing tests on any one equipment shall not be construed as a

waiver for all remaining equipment either of the same type or different type.

3. Responsibility: The Contractor shall assume full responsibility during the factory and field-testing of all equipment and installation provided by him. Should there be any loss or damage to such equipment, materials or the building as result of these tests, the Contractor shall be fully responsible for replacing the damaged equipment and repairing the building. Replacement of damaged equipment shall include all costs, including but not limited to, transportation of, and installation of replacement equipment.

4. Rejection and Retesting

   a. Failure of equipment to withstand tests or to meet ratings shall be sufficient grounds for rejection of equipment.
   b. Any equipment rejected shall be retested in presence of the Engineer, and/or his representative, after rectification. If the modifications or changes are such as to affect any of the drawings, diagrams or any other documents submitted and accepted by the Engineer, revised drawings of diagrams shall be submitted, showing proposed changes and Engineer's approval obtained before changes or modifications are made on the equipment. Modification or changes which do not warrant revision of any drawing, shall be furnished to the Engineer along with notice of retesting.
   c. If it is not possible to rectify rejected equipment, new equipment shall be manufactured and the requirements of the drawings and design calculations of the original unit shall be applicable for the new unit.

5. Cost of Rectification or New Unit: The entire cost of rectification or new unit shall be borne by the Contractor including retesting and cost of witnessing retesting.

6. Costs of Tests: The price for conducting all factory and field tests and checkouts in presence of the Engineer, and/or his representative, including entire cost of rectification, retesting and supplying new unit(s), shall be deemed to be included in the Contract Price. The expense related to travel, lodging and boarding for the Engineer and/or his representative for witnessing of test will, however, be borne by the Authority at no expense to the Contractor, except when retesting is required. In the latter case, all expenses for travel and lodging will be borne by the Contractor as directed by the Engineer. In the event a second retest is required for the same equipment, the Contractor shall bear, in addition to the above costs, the cost of all meals and the hourly payroll costs, including overhead and fringe benefits of the Engineer and/or his representative(s) attending the retest.

C. Factory Tests

1. General: If facilities for conducting any of the tests listed below are not available to the manufacturer, these tests shall be conducted elsewhere by him or by an independent agency as approved by the Engineer. Contractor shall, however, clearly indicate in his proposal, the tests for which manufacturer does not have facilities and intends to submit test reports from an independent agency.

2. AC Switchgear

   a. Following tests listed in ANSI C37.09 as "Design Tests" shall be conducted on one 15 kV class representative circuit breaker with the circuit breaker inserted in its housing:

      1) Rated maximum voltage test
      2) Rated voltage range factor test
      3) Rated frequency test
      4) Rated continuous current carrying tests
      5) Short-circuit rating tests
      6) Momentary current test
      7) Rated standard operating duty tests
      8) Rated permissible tripping delay tests
      9) Rated interrupting time tests
      10) Rated reclosing time tests
      11) Dielectric withstand tests
          - Low frequency withstand voltage tests
          - Impulse withstand voltage tests
      12) Low current switching tests
      13) Radio influence voltage tests as per NEMA SG4

   b. Following tests listed in ANSI C34-09 as "Design Tests" for high voltage circuit breakers shall be conducted on one ground and test device of the 15 kV switchgear, with the ground and test device inserted in the switchgear:

      1) Rated maximum voltage test
      2) Rated frequency test
      3) Short-circuit test to establish the closing and latching capability, applying the short-circuit test supply between the line terminals of the ground and test device and the switchgear ground bus
      4) Momentary current test, applying the test supply between the line terminals of the ground and test device and the switchgear ground bus
      5) Dielectric withstand tests:
          - Low frequency withstand voltage test
          - Impulse withstand voltage test

   c. Following tests listed in ANSI C37.09 as "Production Tests" shall be conducted at the manufacturer's facility on each and every 15 kV class circuit breaker and ground and test device:

      1) Current and linear coupler transformer tests

2) Nameplate check
3) Resistors, heaters, and coil check tests
4) Control and secondary wiring check tests
5) Clearance and mechanical adjustment check tests
6) Mechanical operation tests
7) Timing tests (not required for ground and test device)
8) Stored energy operating mechanism tests
9) Electrical resistance of current path test
10) Low frequency withstand voltage tests

d. Following tests listed in ANSI C37.20 and NEMA SG5 as "Design Tests" shall be conducted on the 15 kV metal-clad AC switchgear assembly:

1) Dielectric tests
- Power frequency withstand tests
- Impulse withstand tests
- Test of busbar insulation

2) Rated continuous current tests
3) Momentary current tests
4) Mechanical operation tests
5) Flame-retardant tests

e. Following tests listed in ANSI C37.20 and NEMA SG5 as "Production Tests" shall be conducted at the manufacturer's facility on the 15 kV metal-clad AC switchgear assembly:

1) Mechanical operation tests
2) Grounding of instrument transformers cases test
3) Electrical operation and control wiring tests
- Control wiring continuity test
- Control wiring insulation test
- Polarity tests
- Functional and sequence tests

4) Checking of indicating instruments and transducers at zero, midpoint and full scale or full output
5) Nameplate check

f. In lieu of Design Tests specified above for AC circuit breakers and AC switchgear assembly, Contractor may submit detailed test certificates from the manufacturer or an independent agency conducted on similar circuit breakers and similar switchgear assemblies for Engineer's review. The Engineer may waive some or all of the tests at his discretion.

3. Rectifier Transformers - Dry Type

a. Following tests shall be conducted at the manufacturer's facility on one representative dry type rectifier transformer:

1) Test to determine that the temperature rise of the windings

is within the permissible limits after delivering full load continuously and fulfilling the duty cycle specified. For this purpose, determine the temperature rise of the windings by resistance after applying 160% load for two hours to a transformer which has already attained steady state temperature rise at 100% continuous load. This value shall not exceed 65˚C at the ambient temperature specified in Article 2.04.B, this Section.

2) Impedance and load loss test at 100% and 160% of rated current on the rated voltage connection of the unit and at extreme taps.
3) Commutating reactance and resistance test as per ANSI C57.18.
4) Full design impulse test at ambient temperature on all transformer terminals. Test to consist of reduced full wave, two chopped waves and a full wave of 110 kV on the HV and 45 kV on the LV windings. Oscillograph records of the applied voltage and neutral current traces shall be submitted with the test reports.
5) Audible sound level test in accordance with C57.12.91. The audible sound level test of rectifier transformer shall be conducted at no load, with the transformer energized at rated voltage and frequency.
6) Insulation power factor test.

b. Following tests listed in ANSI C57.12.91 and ANSI C34.2 shall be conducted at the manufacturer's facility on both rectifier transformers:

1) Resistance measurements on all windings on the rated voltage connection and at all taps.
2) Ratio tests on the rated voltage connection and on all tap connections.
3) Phase-relation tests on the rated voltage connection.
4) Excitation loss test at rated voltage and frequency on the rated voltage connection.
5) Excitation current test at rated voltage and frequency on the rated voltage connection.
6) Dielectric tests:

- Applied voltage
- Induced voltage
- Megger

7) Partial discharge test, in accordance with IEEE-454
8) Nameplate check

4. Rectifiers

a. Following tests listed in ANSI C34.2 shall be conducted on one representative rectifier unit:

1) Rated current test

2) Harmonic analysis test which shall be performed on the AC input and DC output circuits.
3) Audible sound level test, in accordance with NEMA TR 1, except as modified in Article 2.05, this Section. The audible sound level test of rectifier shall be conducted at no load with the rectifier energized at rated voltage and frequency.
4) Reduced voltage, 150% full load current balance test. With load on and temperature stabilized, measure temperature of ambient air in and air out of the rectifier unit, temperature of each of four selected diodes and their associated heat sinks using same positions on each unit and current in each diode.

Note: Increase current by 7% waveform and conduction angle adjustment factor to compensate for loadings by reduced voltage and short circuit.

b. Following tests specified in ANSI C34.2 shall be conducted on both rectifiers:

1) Dielectric tests
2) Rated voltage test
3) Any other manufacturer's standard tests
4) Functional tests
5) Nameplate check

5. Rectifier Surge Voltage and Short Circuit Tests

a. The following tests shall be conducted on one rectifier package consisting of the 15 kV rectifier AC vacuum circuit breaker, rectifier transformer, rectifier and interconnecting bus ducts, all assembled in line. Test setups shall include primary supply system having minimum 150 MVA capacity, protective devices adjusted to provide pick-up values and operating times conforming to those proposed for final installation, shunts, properly calibrated meters and recording oscillographs, shorting devices, loading devices and other associated appurtenances as may be required. The 13.8 kV circuit connecting the AC circuit breaker to the rectifier transformers shall consist of 60-foot length of 3-1/c No. 4/0 AWG cables, or a circuit having equivalent surge impedance. Tests specified, other than the short circuit tests, may be carried out at less than 150 MVA test supply.

b. Open circuit test to ensure ability to withstand transient surge voltages in steps as follows:

1) Energize transformer and rectifier at rated voltage with no load by closing rectifier AC breaker.
2) De-energize transformer and rectifier by tripping rectifier AC circuit breaker.
3) Record voltage wave forms and amplitudes at AC circuit

breaker line side terminals, rectifier transformer high and low voltage terminals, rectifier output terminals and at critical points in surge protection network during close and trip operation.

4) Repeat test a minimum of ten times to ensure maximum transient.
5) Maximum crest of transient surge voltages at AC circuit breaker terminals and rectifier transformer high voltage terminals shall not exceed the value specified in Article 2.03, this Section for the AC circuit breakers.
6) Maximum crest of transient surge impressed on rectifier shall not exceed 75% of the voltage withstand rating of the diodes.

c. Short circuit test to determine short circuit current in steps as follows:

1) Energize a transformer and rectifier at rated voltage with no load.
2) Short rectifier output terminals with shorting device.
3) Clear short (bolted fault) by tripping the rectifier AC circuit breaker by its protective devices.
4) Record current wave form and amplitude at rectifier output terminals during shorting operation.
5) Calculate theoretical values of peak and sustained short circuit currents for rated voltage fault on a 600 MVA system having X/R ratio of 8 and 250 MVA system having X/R ratio of 8. Calculate theoretical transformer overvoltage and the test supply system X/R ratio required to obtain a minimum of these values on actual test set-up for each of the MVA systems specified above.
6) Repeat short circuit test with transformer energized at theoretical overvoltage and the X/R ratio of the test supply system adjusted to the value calculated above. Continue to adjust voltage until calculated peak and sustained values of current are realized.

d. Determine the commutating reactance and resistance of the rectifier package so that the voltage regulation may be calculated to ensure compliance with output voltage characteristics set forth in Article 2.05.D, this Section. Proof shall be provided by the Contractor that methods proposed for measurement of commutating reactance and resistance are accurate and valid to the complete satisfaction of the Engineer. Failing acceptable proof, the Contractor shall perform a voltage regulation test by actual loading of one rectifier package in a method to be specified by the Engineer.

6. Rectifier Current Balance and Load Current Tests

a. The following test shall be conducted on one rectifier package,

including rectifier transformer, rectifier and interconnecting bus ducts, assembled in line. Test set-up shall include necessary supply and loading systems, including switchgear and protective devices, air handling system with temperature controlled at 105˚F, shunts, thermocouples, properly calibrated meters, and associated appurtenances as may be required. Reduced voltage - reduced capacity supply system will be acceptable for certain portion of these tests providing currents specified are increased by 7% wave form and conduction angle adjustment factor to compensate for loading by short circuit. Individual silicon diode junction temperatures shall not exceed design values established in Contractor's load and short circuit calculations as determined from actual case temperature, using Contractor's junction versus case temperature data.

b. Current balance test to ensure compliance with requirement for current balance between paralleled legs in each phase in steps as follows:

    1) Apply 100% full load current and measure diode currents in each paralleled leg in each phase.
    2) Remove one fuse in one leg of each phase so as to create maximum diode current unbalance; then apply 100% full load current and measure diode currents in remaining legs on each phase.
    3) With one fuse removed in one leg of each phase, as in test above, apply 150% full load current for two hours, superimpose five one-minute overloads of 300% full load current and one 15-second overload of 450% full load current as specified in Article 2.05.D, this Section, and measure diode current in the leg which had maximum current in test with 100% load current.

c. Load current test to ensure compliance with rectifier current rating and ability of rectifier to withstand short circuit under load in steps as follows:

    1) With one fuse removed in one leg of each phase as in test above, apply 100% full load current until constant diode temperature is reached.
    2) Apply 150% full load current for two hours immediately after completion of test above with 100% full load current.
    3) Superimpose five one-minute overloads of 300% full load current followed by one 15-second overload of 450% full load current spaced throughout the tow hour period per Article 2.05.D, this Section, during the step described above.
    4) Apply the highest value of short circuit current obtained in the short circuit test above for the operating time of the short time relays plus the rectifier AC circuit breaker opening time in cycles immediately after completion of test above. A time interval of 1-second, maximum, is allowed

between the 450% overload and the application of short circuit.

5) Record load current, ambient air temperature, supply air temperature, discharge air temperature, transformer winding hot-spot temperature, and diode case temperature in leg having maximum current unbalance at sufficiently close time intervals to provide accurate current-time-temperature relationship.
6) Monitor rectifier commutation with oscilloscope during two-hour test loadings set forth in test above to ensure normal operation. If possible, photograph trace or rectifier input voltage waveforms.
7) The above specified current balance test and load current test may be conducted at a lower ambient temperature and the results interpolated for the specified ambient of 105˚F. Supporting data and calculations shall be submitted, together with the test results, to the Engineer for review and approval.

7. Destruction Tests on Diodes

a. Five diodes from a rectifier that has undergone all tests called for in this Section will be selected by the Engineer for the following additional tests. Refer to NEMA-EIA Standards for Silicon Rectifier Diode Stacks RS-282. Test shall be conducted as specified below:
b. One hundred applications of forward current equal to the non-repetitive surge forward current rating under the following conditions:

1) The rectifier diode is operating at its rated working peak reverse voltage, forward current and case temperature prior to surge. The diode may be maintained at its maximum operating temperature before and after the application of surge current without the aid of the forward current.
2) The rectifier diode is required to support its rated working peak reverse voltage during the surge and, following the surge, it must support the rated forward current specified in paragraph 3.a of NEMA-EIA, RS-282, and non-repetitive peak reverse voltage for one-half cycle and then its rated working peak reverse voltage.
3) Successive surges may not be applied until the rectifier diode has returned to the operating conditions specified in NEMA-EIA, RS-282, paragraph 3.a.
4) The one-half cycle surge forward current consists of a single phase, halfwave, 60 Hz sinusoidal pulse. The peak surge forward current is the peak of the halfwave pulse current flowing through the rectifier diode during the surge period. This is the required JEDEC registration data.
5) The surge current for times greater than one-half cycle

consists of a series of halfwave pulses for a specified period of time.

6) No diode failures allowable.

c. Repeat the test above, except that forward surge current application is increased by one thousand amperes. The surviving diodes shall be tested to destruction by increasing forward surge current applications in one thousand ampere increments applied as in steps above, noting the number of surviving diodes for each one thousand ampere test series.

d. Contractor shall supply, and install, at no extra charge to the Authority, five new identical replacement diodes in rectifier from which the subject diodes were removed.

8. DC Switchgear

a. Following tests listed in ANSI C37.14 as "Design Tests" shall be conducted on one representative DC circuit breaker of each rating:

1) Dielectric withstand test
2) Continuous current test
3) Short-circuit current interrupting test: The short circuit test value shall be as calculated for the Substation with the equivalent of three 3,000 kW rectifiers feeding the DC bus. Primary AC system available fault capacity shall be taken as 600 MVA at 13.8 kV and X/R ratio of 10. The fault shall be between the load side terminals of the feeder breaker and the nearest negative bus of the substation. The DC power source shall preferable be from silicon rectifiers. Engineer's approval shall be obtained prior to testing if other sources of supply are to be used. Previous test certifications are not acceptable.
4) Endurance tests

- Electrical endurance test
- Mechanical endurance test

b. Following tests listed in ANSI C37.14 as "Production Tests" shall be conducted at the manufacturer's facility on each and every DC circuit breaker:

1) Calibration test on the individual direct acting trip device prior to final assembly.
2) Control and secondary wiring check test.
3) Dielectric withstand test
4) Mechanical operation test
5) Calibration test on fully assembled circuit breakers

- Direct acting trip devices - The percent error for trip currents versus the calibration marks on the device and the repeatability errors must be within the tolerances specified

in ANSI C37-17 for direct acting trip devices. Two tests shall be conducted on each circuit breaker: first with manufacturer's in-house test supply, the second with the test supply derived from the DC circuit breakers tester furnished by the Contractor and specified in Article 2.12, this Section. Marks shall be stamped on the calibration plate based on actual test results of each circuit breaker.

- Under voltage trip device

6) Manufacturer's standard tests not included in the above tests.

c. Following tests listed in ANSI C37.20, as "Design Tests" shall be conducted on the DC switchgear assembly.

1) Dielectric tests
2) Rated continuous current tests
3) Momentary current tests
4) Short circuit withstand test
5) Flame-retardant tests

d. Following tests listed in ANSI C37.20 as "Production Tests" shall be conducted at the manufacturer's facility on the DC switchgear assembly:

1) Mechanical operation tests
2) Electrical operation and control wiring tests
- Control wiring insulation test
- Polarity tests
- Sequence tests, including operation of load measuring scheme with actual voltages and currents applied. Sequence tests shall be made with breakers in "test" position also with breaker in "connected" position
- Checking of indicating instruments and transducers at zero, midpoint and full scale or full output
- Tests to prove the operation of all devices and indicating instruments, including protective relays, at all settings
3) Nameplate check

9. Bus Ducts

a. Following tests shall be conducted at the manufacturer's facility on one unit of each rating as specified under "Design Tests" in ANSI C37.20 for metal enclosed bus:

1) Dielectric tests
- Power frequency withstand
- Impulse withstand
2) Temperature rise tests
3) Momentary current tests

b. In addition, temperature rise test as described below shall be conducted on one representative anode bus duct.

1) Measure temperature rise of bus conductors in 40˚C ambient at continuous 160% rated load, to be applied until all readings have stabilized. This test may be performed concurrent with the in-line tests specified for rectifier package tests, provided the readings have stabilized, during the two hour application of 160% load. For the purposes of this test, readings will be considered to have stabilized when the rate of temperature rise is less than one degree C per hour.

c. Power frequency withstand tests shall be conducted at the manufacturer's facility on each and every shipping length as specified under "Production Tests" in ANSI C37.20 for metal enclosed buses.

d. If manufacturer submits detailed test report of these tests conducted on similar unit(s) for Engineer's review, Engineer may waive some or all of the design tests at his discretion.

10. Negative Equalizer Bus and Drainage Board

a. Following tests shall be conducted at the manufacturer's facility on the negative equalizer bus and drainage board:

1) Dielectric tests
2) Rated continuous current test
3) Momentary current test
4) Mechanical operation test
5) Electrical operation and control wiring tests:
- Control wiring insulation test
- Polarity tests on diodes and shunts
- Functional and sequence tests
6) Nameplate check

b. If manufacturer submits detailed test reports of the rated continuous current and momentary current tests conducted on similar unit for Engineer's review, the Engineer may waive one or both of these tests at his discretion.

11. 15 kV Breaker Control and Instrument Panel

a. Following tests shall be conducted at the manufacturer's facility on the 15 kV breaker control and instrument panel:

1) Electrical operation and control wiring tests:
- Control wiring continuity test
- Control wiring insulation test
- Functional and sequence tests
2) Checking of indicating instruments at zero, midpoint and full deflection
3) Nameplate check

12. Supervisory Equipment

    a. All tests listed in Contractor-prepared and Engineer's approved factory test procedure shall be conducted on the supervisory equipment at the manufacturer's facility.

D. Field Tests

1. General

    a. Contractor shall perform the following field tests on all equipment specified in this Section after installation of the equipment, and all 15 kV cable testing specified in Section 16120 is complete. Field tests are to be performed to supplement the factory tests and to ensure proper operation of equipment and proper calibration and coordination of protective devices. Contractor shall furnish and set up all special equipment required for these tests, including relay test set, switches, properly calibrated indicating instruments, recording oscillographs, timing devices, shorting devices, loading devices and other associated appurtenances as may be required.
    b. The work includes furnishing of labor, material, test instruments and services necessary to perform required testing and checking of electrical equipment and installation.
    c. All tests shall be successfully completed to show that the installation meets the specification requirements and that the equipment and devices operate as intended, before final acceptance by the Authority.
    d. Tests and checkouts shall be conducted in accordance with the Engineer's approved test procedure specified herein and in National Electrical Code, Massachusetts State Electrical Code and applicable Standards and Specifications of ANSI, NEMA, ICEA, AEIC, etc.
    e. Contractor shall provide properly qualified personnel who shall be responsible for supervising, coordinating, and performing all electrical field testing and checking work and who maintains a written record of all tests conducted. The results of all field tests shall be verified by an independent test laboratory employed by the Contractor.
    f. Testing and checkouts shall be performed in the presence of the Engineer.
    g. Contractor shall furnish four copies of all test results to the Engineer. Results sheets shall include date of test, personnel involved, items tested, type of tests and test data.
    h. Any equipment or material damaged due to improper test procedure or test apparatus handling shall be replaced or restored to original condition by Contractor at his expense.
    i. Safety devices including but not limited to rubber gloves and blankets, screens and barriers, danger signs, padlocks, etc., shall be used to protect and warn all personnel in the vicinity of the tests.

j. All test instruments used shall have a certified calibration sticker showing last date of calibration and expiration date.

2. Field Test Requirements

a. Contractor shall formulate a complete Field Test procedure for all equipment to be furnished and installed under this Section. Test procedure shall be comprehensive and shall include the required tests as specified in relevant standards of ANSI, NEMA and IEEE, supplementing the Factory Test procedure. The detailed procedure for performing the specified short circuit tests shall include step-by-step test procedure supplemented by circuit diagrams, details of instrumentation, safety interlocks and back-up trips provided.

b. The Contractor shall submit the test procedure to the Engineer for review and approval well in advance to the commencement of field tests. Engineer reserves the right to add, delete or make necessary changes in the test procedure. The Contractor is responsible for the performance and installation of the equipment furnished under this Section, he shall, therefore, prior to testing, verify that the installation is proper and in accordance with all applicable installation instructions specified herein.

c. Perform continuity and dielectric tests to prove the correctness of circuitry.

d. Each and every AC and DC circuit breaker shall be thoroughly inspected and certified by the Contractor's Engineer.

e. Check of relay and trip device settings and coordination.

f. Perform function and operation tests of all equipment and of all devices and circuits.

g. Perform phantom load tests on AC switchgear protective devices to ensure calibration as outlined in Article 2.02.D, this Section.

h. Perform short circuit tests on rectifiers and AC and DC switchgear to ensure calibration of rectifier, AC switchgear and DC switchgear protective devices, and overall coordination of protective devices as outlined in Article 2.02.D, this Section, and to confirm adequate short-time current capability or DC circuit breakers. Short circuit tests shall be conducted at the Substation with both rectifiers in service. Circuit breaker of suitable rating furnished by Contractor may be used as a shorting device. Oscillograms of all parameters for each test shall be recorded and furnished with field test reports. Contractor shall conduct the following tests:

1) Energize both rectifiers in the Substation in parallel and close their respective main (rectifier) DC circuit breakers. Short-circuit output terminals of one of the rectifiers. Check for proper protective device coordination and fault isolation as follows:
- Main rectifier DC circuit breaker of short-circuited rectifier should be tripped by its instantaneous reverse

overcurrent trip device, Device 32, to clear the fault supply from the rectifier operating in parallel.
- Device 32 shall also trip the AC circuit breaker of short-circuited rectifier to clear the fault supply from AC system.
- Protective devices of parallel operated rectifier shall not operate during this test.
- Results of test such as total inrush current, steady-state fault current, impulse time of faulted unit, clearing time of faulted unit, primary system voltage and short circuit capacity shall be recorded.

2) Repeat the test, short circuiting the output terminals of the other rectifier instead of the unit in the test above. Check for proper protective device coordination and fault isolation and tabulate the results.
3) Energize any one of the rectifiers in the substation with its main DC breaker closed and close the DC feeder breaker specified by the Engineer. Short circuit the load side of the closed DC feeder breaker. For proper protective device coordination and fault isolation, DC traction feeder breaker instantaneous series overcurrent trip device, Device 176, shall trip the faulted feeder breaker and successfully clear the fault. No other breakers should trip. Tabulate results such as total let-through current and total clearing time, and record primary system voltage and short circuit capacity.
4) Repeat the above test energizing the other rectifier, and short circuit load side of the Engineer Specified DC feeder breaker. For proper protective device coordination and fault isolation, DC traction feeder breaker instantaneous series trip device, Device 176, shall trip the faulted feeder breaker and successfully clear the fault. No other breakers should trip. Tabulate the results of each test as outlined above.
5) Energize both rectifiers in the Substation in parallel closing their respective main (rectifier) DC circuit breakers. Close the DC feeder circuit breaker specified by the Engineer. Short circuit the load side of the closed DC feeder circuit breaker. For proper protective device coordination, fault isolation and DC feeder breaker interrupting capability demonstration, the faulted traction feeder circuit breaker shall be tripped by its instantaneous series trip device, Device 176, and successfully clear the fault. No other breakers should trip. Tabulate the results of test as outlined above.
6) Energize any one of the rectifiers in the Substation and close the main (rectifier) DC circuit breaker. Short-circuit the load terminals of the main (rectifier) DC circuit breaker. For proper protective coordination, rectifier AC circuit breaker of the faulted unit shall be tripped by AC feeder time overcurrent unit of relay Device 50/51. The

short circuit current will flow until interrupted by the AC circuit breaker. Tabulate the results.

7) Equipment and Substation building shall be inspected after each of the above specified tests for damage. Failure of the equipment either to withstand these tests or to coordinate properly or to meet other Specification requirements shall be sufficient grounds for rejection of equipment.

i. Authority's personnel in conjunction with the Contractor shall test each rate-of-rise trip device, Device 150F, in the Substation by placing a short circuit on the far end of the electrical section on which the breaker is used.

1) Testing shall be done with the rate-of-rise device set no lower than 20% above its bottom setting correspondence to a fault farthest away from the breaker. The setting shall allow the start and acceleration of trains at any point in the track section supplied by the circuit breaker, without tripping the rate-of-rise relay.

2) If the breaker fails this test, the Contractor shall adjust or modify the breaker components. The breaker must fully meet the requirements to the satisfaction of the Engineer. Any deviation from these requirements will be considered cause for rejection of the Contractor's rate-of-rise circuitry.

3) The Contractor will be furnished the track feeder and return circuit impedance data, and related information of track and train equipment.

4) All the work external to the Substation for conducting this test, including furnishing equipment for shorting the third rail shall be provided by the Contractor.

j. Equipment and Instruments

1) Check alignment and proper operation of all equipment including operating mechanisms, clearances, adjustment of contacts, and accessory equipment.

2) Test indicating instruments, such as ammeters, voltmeters, and other instruments, by checking and adjusting pointers on zero scale with no load or voltage applied, also at midpoint and full scale.

3) Check Operation of watthour meters and output from pulse initiator.

4) Check the isolation amplifiers for linearity and gain from 1-volt-to-1-volt through 1-volt-to-100-volt.

k. Supervisory Equipment

1) The supervisory equipment at the Substation and in the High Street Operation Center supplied under this Section shall be tested in accordance with Contractor-prepared, Engineer-approved test procedure.

2) All status, control and analog functions shall be individually tested and checked out and the results recorded, individually, in test report. Analog devices shall be

checked for linearity at zero, 50% and 100% output and calibrated for proper output to SCADA.

3) Qualified technical representative(s) of equipment manufacturer shall be employed by the Contractor to assist him and the Authority in testing and checkout of the equipment and in making the necessary changes to the existing SCADA software.

l. 600 Volt Wire and Cable

1) Test in accordance with Article 3.02.B, Section 16050.

m. Grounding

1) Test in accordance with Article 3.08, Section 16450.

E. Test Reports

1. The Contractor shall submit five certified copies of test reports for all the tests conducted at the factory and in field for the Engineer's approval. Test reports shall be submitted to the Engineer within seven (7) days after completion of tests. In case of "Design Tests" and tests on rectifier packages, test reports shall include original data, detailed calculation of test data used to arrive at the results and interpretation of results. Test reports shall contain the characteristics, curves, etc. where required for interpretation of results.

2. Result of AC and DC circuit breaker function test shall be tabulated individually for each breaker, indicating each function tested. Suggested tabulations for recording these tests are included in Appendix P.

PART 4 - MEASUREMENT AND PAYMENT

0.1 MEASUREMENT

A. The work included in this Section will not be measured separately but will be paid for at the Contract lump sum or unit prices.

B. Payment for 15 kV AC switchgear, 750 volt DC switchgear, anode and cathode buses, negative equalizer bus and drainage board, station battery and charger, SCADA RTU and one-on-one supervisory system MTU and RTU and 15 kV breaker control and instrument panel will be made at the Contract lump sum prices. Payment for rectifier transformers will be made at the Contract unit prices. Such price and payment shall represent full compensation for completing the work, including furnishing all equipment, materials, labor, tools and incidentals necessary to complete the work.

C. Payment for furnishing, installing and testing low voltage power, control and supervisory system wiring, conduit system and supports, cable trays and supports and all other material required for supplying, controlling and

interconnecting the equipment furnished under this Section, will be made at the Contract lump sum price. Such price and payment shall represent full compensation for completing the work including all labor, materials, equipment and incidentals necessary to complete the work.

D. Payment for providing additional equipment and making hardware and software changes to MBTA existing SCADA master terminal equipment at the High Street Operations' Center, which requires Engineer's authorization prior to performing the work, will be covered as an Allowance Item on the condition of payment described in Article 1.05, Paragraph B (2), Section 01150 of Division 1 - General Requirements. The allowance will be adjusted for the actual amount paid for the required work approved by the Engineer.

0.2 PAYMENT

Item No.	Payment Items	Unit
5075.000	FURNISH, INSTALL, TEST & COMM. 13 UNIT 15 KV AC SWGR. INCLUD. AUX. EQUIPMENT	LUMP SUM
5076.000	FURNISH, INSTALL, TEST & COMM. RECT. X'FORMER FOR 3000 KW RECT. INCLUD. AUX. EQUIPMENT	EACH
5077.000	FURNISH, INSTALL, TEST & COMM. 3000 KW SILICON DIODE RECTIFIER INCLUD. AUX. EQUIPMENT	EACH
5078.000	FURNISH, INSTALL, TEST & COMM. 10 UNIT 750-VOLT DC SWGR. INCLUD. AUX. EQUIPMENT	LUMP SUM
5079.000	FURNISH, INSTALL, TEST & COMM. ANODE & CATHODE POS. & NEG. BUS DUCTS FOR RECT. #1 PKG.	LUMP SUM
5080.000	FURNISH, INSTALL, TEST & COMM. ANODE & CATHODE POS. & NEG. BUS DUCTS FOR RECT. #2 PKG.	LUMP SUM
5081.000	FURNISH, INSTALL, TEST & COMM. NEGATIVE EQUALIZER BUS & DRAINAGE BOARD	LUMP SUM
5082.000	FURNISH, INSTALL, TEST & COMM. STATION BATTERY, CHARGER, RACK & 125 VOLT DC PANEL	LUMP SUM
5083.000	RTU & REMOTE MASTER UNIT FOR ONE-ON-ONE SUPV. SYSTEM & RTU	LUMP SUM

	FOR SCADA SYSTEM	
5083.100	RTU FOR PASSENGER STATION UNIT SUBSTATION	LUMP SUM
5084.000	FURNISH, INSTALL, TEXT & COMM. 15 KV BKR. CONTROL & INSTRUMENT PNL.	LUMP SUM
5118.000	HARDWARE & SOFTWARE CHANGES ALLOWANCE & ADDITIONS TO SCADA SYSTEM AT HIGH ST. FOR SUBSTATION CONTROLS.	
5119.000	FURNISH & INSTALL LV CABLES, CONDUITS, TRAYS, SUPPORTS FOR TRACTION PWR. EQUIP. AT SUBSTATION	LUMP SUM

TABLE 1

Transient RMS Factor K, As Related To System X/R Ratio

END OF SECTION